Back

Back

CHAPTER 18

Electrical Energy and Capacitance

PHYSICS IN ACTION

During a thunderstorm, particles having different charges accumulate in different parts of a cloud. This separation of charges creates an electric field between a cloud and the ground. Normally, the charges remain separate because air is a nearly perfect insulator. But as charges continue to accumulate, the strength of the electric field increases, creating a potential difference of as much as 100 million volts. As the potential difference increases, a crucial *breakdown voltage* is sometimes reached; that is, the air is ionized by the potential difference and becomes a conductor. Electric charge then flows between the cloud and the ground, an event we perceive as lightning in the sky.

- *What is the relationship between electric potential and the electric field?*
- *How is a thunderstorm like a large natural capacitor?*

CONCEPT REVIEW

- **Potential energy (Section 5-2)**
- **Electric field (Section 17-3)**

Back

18-1
Electrical potential energy

18-1 SECTION OBJECTIVES

- **Define electrical potential energy.**
- **Compute the electrical potential energy for various charge distributions.**

electrical potential energy

potential energy associated with an object due to its position relative to a source of electric force

ELECTRICAL ENERGY AND ELECTRIC FORCE

When two charges interact, there is an electric force between them, as described in Chapter 17. As with the gravitational force associated with an object's position relative to Earth, there is a potential energy associated with this force. This kind of potential energy is called **electrical potential energy.** Unlike gravitational potential energy, electrical potential energy results from the interaction of two objects' charges, not their masses.

Electrical potential energy is a form of mechanical energy

Mechanical energy is conserved as long as friction and radiation are not present. As with gravitational and elastic potential energy, electrical potential energy can be included in the expression for mechanical energy (see Chapter 5). If gravitational force, elastic force, and electric force are all acting on an object, the mechanical energy can be written as follows:

$$ME = KE + PE_{grav} + PE_{elastic} + PE_{electric}$$

To account for the forces (except friction) that may also be present in a problem, the appropriate potential-energy terms associated with each force are added to the expression for mechanical energy.

Any time a charge moves because of an electric force, whether from a uniform electric field or from another charge or group of charges, work is done on that charge. For example, in **Figure 18-1,** the electrical potential energy associated with each charge decreases as the charge moves.

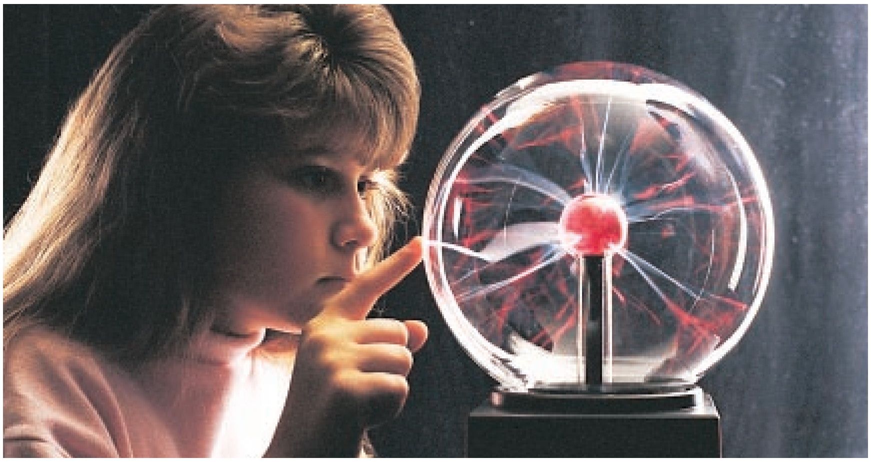


Figure 18-1
As the charges in these sparks move, the electrical potential energy decreases, just as gravitational potential energy decreases as an object falls.

Back

Electrical potential energy can be associated with a charge in a uniform field

Consider a positive charge in a uniform electric field. (A uniform field is a field that has the same value and direction at all points.) Assume the charge is displaced at a constant velocity *in the same direction as the electric field,* as shown in **Figure 18-2.**

There is a change in the electrical potential energy associated with the charge's new position in the electric field. The change in the electrical potential energy depends on the charge, q, as well as the strength of the electric field, E, and the displacement, d. It can be written as follows:

$$\Delta PE_{electric} = -qE\Delta d$$

The negative sign indicates that the electrical potential energy will increase if the charge is negative and decrease if the charge is positive.

As with other forms of potential energy, it is the *difference* in electrical potential energy that is physically important. If the displacement in the expression above is chosen so that it is the distance in the direction of the field from the reference point, or zero level, then the initial electrical potential energy is zero and the expression can be rewritten as shown below. As with other forms of energy, the SI unit for electrical potential energy is the joule (J).

ELECTRICAL POTENTIAL ENERGY IN A UNIFORM ELECTRIC FIELD

$$PE_{electric} = -qEd$$

electrical potential energy =
−(charge × electric field strength × displacement from the reference point in the direction of the field)

This equation is valid only for a uniform electric field. As described in Chapter 17, the electric field lines for a point charge are farther apart as the distance from the charge increases. Thus, the electric field of a point charge is an example of a nonuniform field because the field strength decreases as distance from the charge increases.

When electrical potential energy is calculated, d is the magnitude of the displacement's component *in the direction of the electric field.* Any displacement of the charge in a direction perpendicular to the electric field does not change the electrical potential energy. This is similar to gravitational potential energy, in which only the vertical distance from the zero level is important.

Electrical potential energy can be associated with a pair of charges

Recall that a single point charge produces a nonuniform electric field. If a second charge is placed nearby, there will be an electrical potential energy associated with the two charges. Because the electric field is not uniform, the electrical potential energy of the system of two charges requires a different expression.

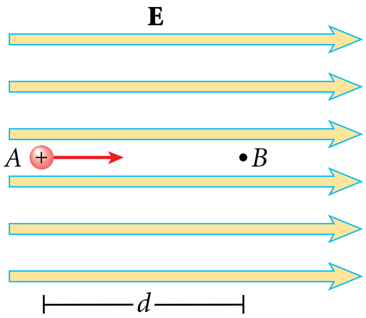


Figure 18-2
A positive charge moves from point *A* to point *B* in a uniform electric field, and the potential energy changes as a result.

internetconnect
SCILINKS NSTA
TOPIC: Electrical energy
GO TO: www.scilinks.org
***sci*LINKS CODE:** HF2181

Back

ELECTRICAL POTENTIAL ENERGY FOR A PAIR OF CHARGES

$$PE_{electric} = k_C \frac{q_1 q_2}{r}$$

$$\textbf{electrical potential energy} = \textbf{Coulomb constant} \times \frac{\textbf{charge 1} \times \textbf{charge 2}}{\textbf{distance}}$$

The quantity k_C is the *Coulomb constant,* which has an approximate value of $8.99 \times 10^9\ \mathrm{N \bullet m^2/C^2}$.

There are several things to keep in mind regarding this expression. First, the reference point for the electrical potential energy is assumed to be at infinity. This can be verified by noting that the electrical potential energy goes to zero as the distance between the charges, r, goes to infinity. Second, because like charges repel, positive work must be done to bring them together, so the electrical potential energy is positive for like charges and negative for unlike charges.

This expression can be used to determine the electrical potential energy associated with more than two charges. In such cases, determine the electrical potential energy associated with *each pair* of charges, and then add the energies.

SAMPLE PROBLEM 18A

Electrical potential energy

PROBLEM

The electrical potential energy associated with an electron and a proton is -4.35×10^{-18} J. What is the distance between these two charges?

SOLUTION

Given: $q_1 = -1.60 \times 10^{-19}$ C $\quad q_2 = +1.60 \times 10^{-19}$ C

$PE_{electric} = -4.35 \times 10^{-18}$ J

Unknown: $r = ?$

Use the equation for the electrical potential energy associated with a pair of charges:

$$PE_{electric} = k_C \frac{q_1 q_2}{r}$$

Rearrange to solve for r:

$$r = k_C \frac{q_1 q_2}{PE_{electric}}$$

$$r = (8.99 \times 10^9\ \mathrm{N \bullet m^2/C^2}) \left(\frac{(-1.60 \times 10^{-19}\ \mathrm{C})(1.60 \times 10^{-19}\ \mathrm{C})}{(-4.35 \times 10^{-18}\ \mathrm{J})} \right)$$

$$\boxed{r = 5.29 \times 10^{-11}\ \mathrm{m}}$$

Back

PRACTICE 18A

Electrical potential energy

1. Two alpha particles (helium nuclei), each consisting of two protons and two neutrons, have an electrical potential energy of 6.32×10^{-19} J. What is the distance between these particles at this time?

2. Two charges are located along the x-axis. One has a charge of 6.4 μC, and the second has a charge of −3.2 μC. If the electrical potential energy associated with the pair of charges is -4.1×10^{-2} J, what is the distance between the charges?

3. In a charging process, 10^{13} electrons are removed from a metal sphere and placed on a second sphere that is initially uncharged. Then the electrical potential energy associated with the two spheres is found to be -7.2×10^{-2} J. What is the distance between the two spheres?

4. A charge moves a distance of 2.0 cm in the direction of a uniform electric field having a magnitude of 215 N/C. The electrical potential energy of the charge decreases by 6.9×10^{-19} J as it moves. Find the magnitude of the charge on the moving particle. (Hint: The electrical potential energy depends on the distance moved in the direction of the field.)

Section Review

1. What is the difference between $\Delta PE_{electric}$ and $PE_{electric}$?

2. In a uniform electric field, what factors does the electrical potential energy depend on?

3. Describe the conditions that are necessary for mechanical energy to be a conserved quantity.

4. Is there a single correct reference point from which all electrical potential energy measurements must be taken?

5. A uniform electric field with a magnitude of 250 N/C is directed in the positive x direction. A 12 μC charge moves from the origin to the point (20.0 cm, 50.0 cm). What is the change in the electrical potential energy of the system as a result of the change in position of this charge?

6. **Physics in Action** What is the change in the electrical potential energy in a lightning bolt if 35 C of charge travel to the ground from a cloud 2.0 km above the ground in the direction of the field? Assume the electric field is uniform and has a magnitude of 1.0×10^{6} N/C.

18-2
Potential difference

18-2 SECTION OBJECTIVES

- **Distinguish between electrical potential energy, electric potential, and potential difference.**
- **Compute the electric potential for various charge distributions.**

CHANGING ELECTRIC POTENTIAL

Electrical potential energy is useful in solving problems, particularly those involving charged particles. But at any point in an electric field, as the value of the charge increases, the value of the electrical potential energy increases. A more practical concept in the study of electricity is **electric potential.**

electric potential

the electrical potential energy associated with a charged particle divided by the charge of the particle

The electric potential at some point is defined as the electrical potential energy associated with a charged particle in an electric field divided by the charge of the particle.

$$V = \frac{PE_{electric}}{q}$$

Although a greater charge will involve a greater amount of electrical potential energy, the ratio of that energy to the charge is the same as it would be if a smaller charge were at the same position in the field. In other words, the electric potential at a point *is independent of the charge at that point.*

Potential difference is a change in electric potential

potential difference

the change in electrical potential energy associated with a charged particle divided by the charge of the particle

Because the reference point for measuring electrical potential energy is arbitrary, the reference point for measuring electric potential is also arbitrary. Thus, only changes in electric potential are significant. The **potential difference** between two points can be expressed as follows:

POTENTIAL DIFFERENCE

$$\Delta V = \frac{\Delta PE_{electric}}{q}$$

$$\text{potential difference} = \frac{\text{change in electrical potential energy}}{\text{electric charge}}$$

Potential difference is a measure of the change in the electrical potential energy divided by the charge. The SI unit for potential difference (and electric potential) is the *volt,* V, and is equivalent to one joule per coulomb. As a 1 C charge moves through a potential difference of 1 V, the charge gains (or loses) 1 J of energy. The potential difference between the two terminals of a battery, for instance, can range from about 1.5 V for a small battery to about 12 V for a car battery like the one shown in **Figure 18-3.** The potential difference between the two slots in a household electrical outlet is about 120 V.

Figure 18-3
For a typical car battery, there is a potential difference of 12 V between the negative (black) and the positive (red) terminals.

Back

Remember that only electrical potential energy is a quantity of energy, with units in joules. Electric potential and potential difference are both measures of energy per unit charge (measured in units of volts), and potential difference describes a change in energy per unit charge.

Did you know?

A unit of energy commonly used in atomic and nuclear physics that is convenient because of its small size is the *electron volt,* eV. It is defined as the energy that an electron (or proton) gains when accelerated through a potential difference of 1 V. One electron volt is equal to 1.60×10^{-19} J.

The potential difference in a uniform field varies with the displacement from a reference point

The expression for potential difference can be combined with the expressions for electrical potential energy. The resulting equations are often simpler to apply in certain situations. For example, consider the electrical potential energy of a charge in a uniform electric field.

$$PE_{electric} = -qEd$$

This can be substituted into the equation for potential difference.

$$\Delta V = \frac{\Delta PE_{electric}}{q}$$

$$\Delta V = \frac{\Delta(-qEd)}{q}$$

As the charge moves in the electric field, the only quantity in the parentheses that changes is the displacement from the reference point. Thus, the potential difference in this case can be rewritten as follows:

POTENTIAL DIFFERENCE IN A UNIFORM ELECTRIC FIELD

$$\Delta V = -E\Delta d$$

potential difference =
−(magnitude of the electric field × displacement)

Again, keep in mind that the quantity Δd in this expression is the displacement moved in the direction of the field. Any displacement perpendicular to the field does not change the electrical potential energy.

The reference point for potential difference near a point charge is often at infinity

In Section 18-1, we were given the expression for the electrical potential energy associated with a pair of charges. To determine the potential difference between two points in the field of a point charge, we first calculate the electric potential associated with each point. Imagine a point charge q_2 in the electric field of a point charge q_1 at point B some distance away, as shown in **Figure 18-4.** The electric potential at point A due to q_1 can be expressed as follows:

$$V = \frac{PE_{electric}}{q_2} = k_C\frac{q_1q_2}{rq_2} = k_C\frac{q_1}{r}$$

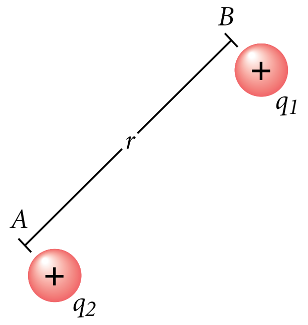


Figure 18-4
The electric potential at point *A* depends on the charge at point *B* and the distance *r*.

Back

Do not confuse the two charges in this example. The charge q_1 is responsible for the electric potential at point A. Therefore, *an electric potential exists at some point in an electric field regardless of whether there is a charge at that point.* In this case, the electric potential at a point depends on only two quantities: the charge responsible for the electric potential (in this case q_1) and the distance r from this charge to the point in question.

To determine the potential difference between any two points near the point charge q_1, first note that the electric potential at each point depends only on the distance from each point to the charge q_1. If the two distances are r_1 and r_2, then the potential difference between these two points can be written as follows:

$$\Delta V = k_C\frac{q_1}{r_2} - k_C\frac{q_1}{r_1} = k_C q_1\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

If the distance r_1 between the point and q_1 is large enough, it is assumed to be infinitely far from the charge q_1. In that case, the quantity $1/r_1$ is zero. The expression then simplifies to the following (dropping the subscripts):

POTENTIAL DIFFERENCE BETWEEN A POINT AT INFINITY AND A POINT NEAR A POINT CHARGE

$$\Delta V = k_C\frac{q}{r}$$

$$\textbf{potential difference} = \textbf{Coulomb constant} \times \frac{\textbf{value of the point charge}}{\textbf{distance to the point charge}}$$

This result for the potential difference associated with a point charge appears identical to the electric potential associated with a point charge. The two expressions look the same only because we have chosen a special reference point from which to measure the potential difference.

The superposition principle can be used to calculate the electric potential for a group of charges

The electric potential at a point near two or more charges is obtained by applying a rule called the *superposition principle.* This rule states that the total electric potential at some point near several point charges is the algebraic sum of the electric potentials resulting from each of the individual charges. While this is similar to the method used in Chapter 17 to find the resultant electric field at a point in space, here the summation is much easier to evaluate because the electric potentials are scalar quantities, not vector quantities. There are no components to worry about.

To evaluate the electric potential at a point near a group of point charges, you simply take the algebraic sum of the potentials resulting from all charges. Remember, you must keep track of signs. The electric potential at some point near a positive charge is positive, and the potential near a negative charge is negative.

Did you know?

The volt is named after the Italian physicist Alessandro Volta (1745–1827), who developed the first practical electric battery, known as a voltaic pile. Because potential difference is measured in units of volts, it is sometimes referred to as *voltage*.

Back

SAMPLE PROBLEM 18B

Potential difference

PROBLEM

A 5.0 μC point charge is at the origin, and a point charge of −2.0 μC is on the *x*-axis at (3.0 m, 0.0 m), as shown in Figure 18-5. Find the total potential difference resulting from these charges between point *P*, with coordinates (0.0 m, 4.0 m), and a point infinitely far away.

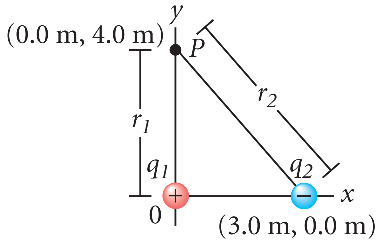


Figure 18-5

SOLUTION

Given: $q_1 = 5.0 \times 10^{-6}$ C $\quad q_2 = -2.0 \times 10^{-6}$ C

$r_1 = 4.0$ m

Unknown: $\Delta V = ?$

Use the equation for the potential difference near a point charge.

$$\Delta V_1 = k_C \frac{q_1}{r_1} = \left(8.99 \times 10^9 \frac{\text{N}\bullet\text{m}^2}{\text{C}^2}\right)\left(\frac{5.0 \times 10^{-6}\ \text{C}}{4.0\ \text{m}}\right) = 1.1 \times 10^4\ \text{V}$$

$$r_2 = \sqrt{(3.0\ \text{m})^2 + (4.0\ \text{m})^2} = \sqrt{25\ \text{m}^2} = 5.0\ \text{m}$$

$$\Delta V_2 = k_C \frac{q_2}{r_2} = \left(8.99 \times 10^9 \frac{\text{N}\bullet\text{m}^2}{\text{C}^2}\right)\left(\frac{-2.0 \times 10^{-6}\ \text{C}}{5.0\ \text{m}}\right) = -0.36 \times 10^4\ \text{V}$$

$$\Delta V = \Delta V_1 + \Delta V_2 = (1.1 \times 10^4\ \text{V}) - (0.36 \times 10^4\ \text{V})$$

$$\boxed{\Delta V = 7000\ \text{V}}$$

PRACTICE 18B

Potential difference

1. Find the potential difference between a point infinitely far away and a point 1.0 cm from a proton.

2. Two point charges of magnitude 5.0 nC and −3.0 nC are separated by 35.0 cm. What is the potential difference between a point infinitely far away and a point midway between the charges?

3. Four particles with charges of 5.0 μC, 3.0 μC, 3.0 μC, and −5.0 μC are placed at the corners of a 2.0 m × 2.0 m square. Determine the potential difference between the center of the square and infinity.

internetconnect

SCILINKS NSTA

TOPIC: Batteries
GO TO: www.scilinks.org
***sci*LINKS CODE:** HF2182

A battery does work to move charges

One of the best applications of the concepts of electric potential and potential difference is in the operation of a battery in some electrical apparatus. The battery is useful when it is connected by conducting wires to devices such as light bulbs, radios, power windows, motors, and so forth.

Recall that the reference point for determining the electric potential at some point is arbitrary. When a battery is connected by conductors to an electrical device, the reference point is often defined by *grounding* some point of the arrangement. (A point is said to be grounded when it is connected to an object having an electric potential of zero.) For example, imagine a typical 12 V automobile battery. Such a battery maintains a potential difference across its terminals, where the positive terminal is 12 V higher in potential than the negative terminal. If the negative plate of the battery is grounded, the positive plate would then have a potential of 12 V.

Consumer Focus — *Finding the Right Battery*

"Heavy duty," "long-lasting alkaline," and "environmentally friendly rechargeable" are some of the labels that manufacturers put on batteries. But how do you know which one is the best?

The answer depends on how you will use it. Some batteries are used continuously, but others are turned off and on frequently, as in a stereo. Still others must be able to hold a charge without being used, especially if they will be used in smoke detectors and flashlights.

In terms of price, "heavy duty" batteries typically cost the least, but they last only about 30 percent as long as alkaline batteries. This makes them prohibitively expensive for most uses and makes them an unnecessary source of landfill clutter.

Alkaline batteries are more expensive but have longer lives, lasting up to 6 h in continuous use and up to 18 h in intermittent use. They hold a full charge for years, making them good for use in flashlights and similar devices. They are now less of an environmental problem because manufacturers stopped using mercury in such products several years ago. However, because they are single-use batteries, they also end up in landfills very quickly.

Rechargeable cells are the most expensive to purchase initially. They can cost up to $8, but if recycled, they are the most economical in the long term and are the most environmentally sound choice. These cells, often called NiCads because they contain nickel (Ni) and cadmium (Cd) metals, can be recharged hundreds of times. Although NiCads last only about half as long on one charge as alkaline batteries, the electricity to recharge them costs pennies. NiCads lose about 1 percent of their stored energy each day they are not used and should therefore never be put in smoke detectors or flashlights.

Back

Now imagine a charge of 1 C moving around a battery connected to an electrical device. The charge moves inside the battery from the negative terminal (which is at an electrical potential of 0 V) to the positive terminal (which is at an electrical potential of 12 V). The electric field inside the battery does work on the charge to move it from the negative terminal to the positive terminal and to increase the electrical potential energy associated with the charge. The net result is an electrical potential increase of 12 V. This means that every coulomb of positive charge that leaves the positive terminal of the battery is associated with a total of 12 J of electrical potential energy.

As charge moves through the conductors and devices toward the negative battery terminal, it gives up its 12 J of electrical potential energy to the external devices. When the charge reaches the negative terminal, its electrical potential energy is zero. At this point, the battery provides another 12 J of energy to the charge as it is moved from the negative terminal to the positive terminal of the battery, allowing the charge to make another transit of the device and battery.

CONCEPT PREVIEW

The role of batteries in electric circuits will be discussed further in Chapters 19 and 20.

Section Review

1. The gap between electrodes in a spark plug is 0.060 cm. To produce an electric spark in a gasoline-air mixture, there must be an electric field of 3.0×10^6 V/m. What minimum potential difference must be supplied by the ignition circuit to start a car?
2. Given the electrical potential energy, how do you calculate electric potential?
3. Why is electric potential a more useful quantity for most calculations than electrical potential energy?
4. Explain how electric potential and potential difference are related. What units are used for each one?
5. A proton is released from rest in a uniform electric field with a magnitude of 8.0×10^4 V/m. The proton is displaced 0.50 m as a result.
   a. Find the potential difference between the proton's initial and final positions.
   b. Find the change in electrical potential energy of the proton as a result of this displacement.
6. **Physics in Action** In a thunderstorm, the air must be ionized by a high voltage before a conducting path for a lightning bolt can be created. An electric field of about 1.0×10^6 V/m is required to ionize dry air. What would the breakdown voltage in air be if a thundercloud were 1.60 km above ground? Assume that the electric field between the cloud and the ground is uniform.

Back

18-3
Capacitance

18-3 SECTION OBJECTIVES

- **Relate capacitance to the storage of electrical potential energy in the form of separated charges.**
- **Calculate the capacitance of various devices.**
- **Calculate the energy stored in a capacitor.**

CAPACITORS AND CHARGE STORAGE

A capacitor is a device that is used in a variety of electric circuits to perform many functions. Uses include tuning the frequency of radio receivers, eliminating sparking in automobile ignition systems, and storing energy in electronic flash units.

A charged capacitor is useful because it acts as a storehouse of charge and energy that can be reclaimed when needed for a specific application. A typical design for a capacitor consists of two parallel metal plates separated by a small distance. This type of capacitor is called a *parallel-plate capacitor.*

When used in an electric circuit, the plates are connected to the two terminals of a battery or other potential difference, as shown in **Figure 18-6.** When this connection is made, charges are removed from one of the plates, leaving the plate with a net charge. An equal and opposite amount of charge accumulates on the other plate. Charge transfer between the plates stops when the potential difference between the plates is equal to the potential difference between the terminals of the battery. This charging process is illustrated in **Figure 18-6(b).**

Capacitance is the ratio of charge to potential difference

capacitance

the ability of a conductor to store energy in the form of electrically separated charges

The ability of a conductor to store energy in the form of electrically separated charges is measured by the **capacitance** of the conductor. The capacitance is defined as the ratio of the net charge on each plate to the potential difference created by the separated charges.

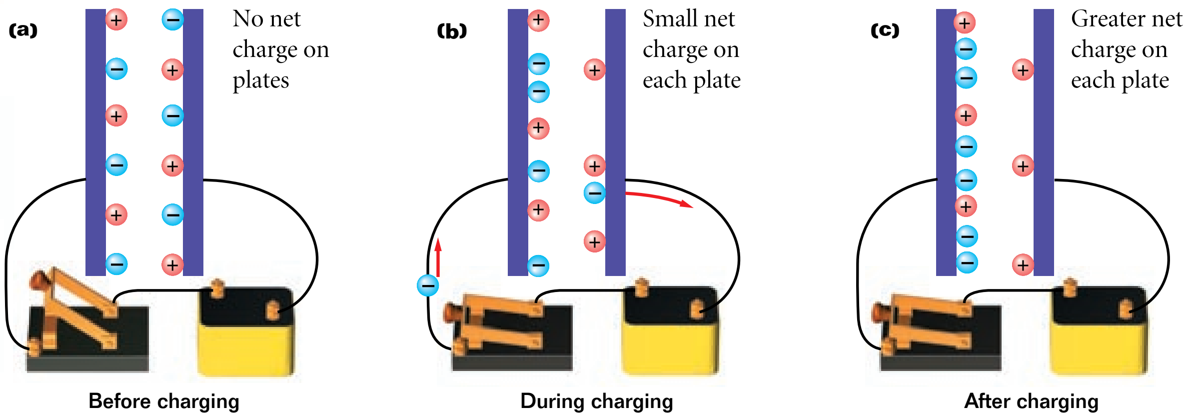


Figure 18-6
When connected to a battery, the plates of a parallel-plate capacitor become oppositely charged.

Back

CAPACITANCE

$$C = \frac{Q}{\Delta V}$$

$$\text{capacitance} = \frac{\text{magnitude of charge on each plate}}{\text{potential difference}}$$

The SI unit for capacitance is the *farad*, F, which is equivalent to a coulomb per volt (C/V). In practice, most typical capacitors have capacitances ranging from microfarads ($1\ \mu F = 1 \times 10^{-6}$ F) to picofarads ($1\ pF = 1 \times 10^{-12}$ F).

Capacitance depends on the size and shape of the capacitor

The capacitance of a parallel-plate capacitor with no material between its plates is given by the following expression:

CAPACITANCE FOR A PARALLEL-PLATE CAPACITOR IN A VACUUM

$$C = \varepsilon_0 \frac{A}{d}$$

$$\text{capacitance} = \text{permittivity of a vacuum} \times \frac{\text{area of one of the plates}}{\text{distance between the plates}}$$

In this expression, the Greek letter ε (epsilon) represents a constant called the *permittivity* of the medium. When it is followed by a subscripted zero, it refers to a vacuum. It has a magnitude of $8.85 \times 10^{-12}\ C^2/N{\bullet}m^2$.

Notice that the amount of charge a parallel-plate capacitor can store for a given potential difference increases as the plate area increases. A capacitor constructed from large plates has a larger capacitance than one having small plates if their plate separations are the same. For a given potential difference, the charge on the plates—and thus the capacitance—increases with decreasing plate separation (d).

Suppose an isolated conducting sphere has a radius R and a charge Q. The potential difference between the surface of the sphere and infinity is the same as it would be for an equal point charge at the center of the sphere.

$$\Delta V = k_C \frac{Q}{R}$$

Substituting this expression into the definition of capacitance results in the following expression:

$$C_{sphere} = \frac{Q}{\Delta V} = \frac{Q}{k_C\left(\frac{Q}{R}\right)} = \frac{R}{k_C}$$

Did you know?

The farad is named after Michael Faraday (1791–1867), a prominent nineteenth-century English chemist and physicist. Faraday made many contributions to our understanding of electromagnetic phenomena.

internet**connect**

SCILINKS NSTA

TOPIC: Michael Faraday
GO TO: www.scilinks.org
***sci*LINKS CODE:** HF2184

Back

internetconnect

SCILINKS
NSTA
TOPIC: Capacitors
GO TO: www.scilinks.org
***sci*LINKS CODE:** HF2183

This equation indicates that the capacitance of a sphere increases as the size of the sphere increases. Because Earth is so large, it has an extremely large capacitance. This means that Earth can provide or accept a large amount of charge without its electric potential changing too much. This is why Earth is often used as a ground in electric circuits. The ground is the reference point from which the potential differences in a circuit are measured, so it is important that this reference point not change.

The material between the plates of a capacitor can change its capacitance

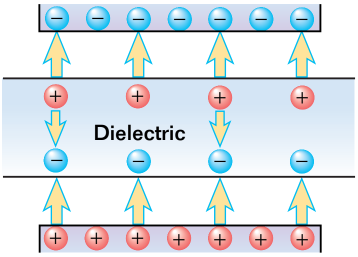


Figure 18-7
The effect of a dielectric is to reduce the strength of the electric field in a capacitor.

So far, we have assumed that the space between the plates of a parallel-plate capacitor is a vacuum. However, in many parallel-plate capacitors, the space is filled with a material called a *dielectric.* A dielectric is an insulating material, such as air, rubber, glass, or waxed paper. When a dielectric is inserted between the plates of a capacitor, the capacitance increases. This is because the molecules in a dielectric can align with the applied electric field, causing an excess negative charge near the surface of the dielectric at the positive plate and an excess positive charge near the surface of the dielectric at the negative plate. The surface charge on the dielectric effectively reduces the charge on the capacitor plates, as shown in **Figure 18-7.** Thus, the plates can store more charge for a given potential difference. According to the expression $Q = C\Delta V$, if the charge increases and the potential difference is constant, the capacitance must increase. A capacitor with a dielectric can store more charge and energy for a given potential difference than can the same capacitor without a dielectric. In this book, problems will assume that capacitors are in a vacuum, with no dielectrics.

Discharging capacitors rapidly release their charge

Once a capacitor is charged, the battery or other source of potential difference that charged it can be removed from the circuit. The two plates of the capacitor will remain charged unless they are connected with a material that conducts. Once the plates are connected, the capacitor will *discharge.* This process

Conceptual Challenge

1. Charge on a capacitor plate A certain capacitor is designed so that one plate is large and the other is small. Do the plates have the same charge when connected to a battery?

2. Capacitor storage What does a capacitor store, given that the net charge in a parallel-plate capacitor is always zero?

Back

is the opposite of charging. The charges move back from one plate to another until both plates are uncharged again because this is the state of lowest potential energy.

One device that uses a capacitor is the flash attachment of a camera. A battery is used to charge the capacitor, and this stored charge is then released when the shutter-release button is pressed to take a picture. One advantage of using a discharging capacitor instead of a battery to power a flash is that with a capacitor, the stored charge can be delivered to a flash tube much faster, illuminating the subject at the instant more light is needed.

Computers make use of capacitors in many ways. For example, one type of computer keyboard has capacitors at the base of its keys, as shown in **Figure 18-8.** Each key is connected to a movable plate, which represents one side of the capacitor. The fixed plate on the bottom of the keyboard represents the other side of the capacitor. When a key is pressed, the capacitor spacing decreases, causing an increase in capacitance. External electronic circuits recognize that a key has been pressed when its capacitance changes.

Because the area of the plates and the distance between the plates can be controlled, the capacitance, and thus the electric field strength, can also be easily controlled.

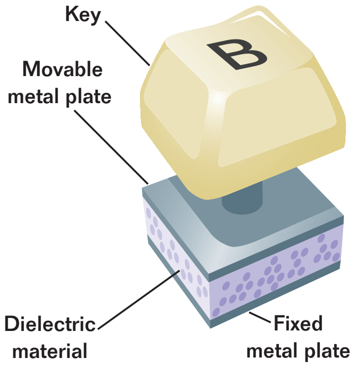


Figure 18-8
A parallel-plate capacitor is often used in keyboards.

ENERGY AND CAPACITORS

A charged capacitor stores electrical potential energy because it requires work to move charges through a circuit to the opposite plates of a capacitor. The work done on these charges is a measure of the transfer of energy (see Chapter 5).

For example, if a capacitor is initially uncharged so that the plates are at the same electric potential, that is, if both plates are neutral, then almost no work is required to transfer a small amount of charge from one plate to the other. However, once a charge has been transferred, a small potential difference appears between the plates. As additional charge is transferred through this potential difference, the electrical potential energy of the system increases. This increase in energy is the result of work done on the charge. The electrical potential energy stored in a capacitor that is charged from zero to some charge, Q, is given by the following expression:

ELECTRICAL POTENTIAL ENERGY STORED IN A CHARGED CAPACITOR

$$PE_{electric} = \frac{1}{2}Q\Delta V$$

electrical potential energy =
$\frac{1}{2}$ (charge on one plate)(final potential difference)

Back

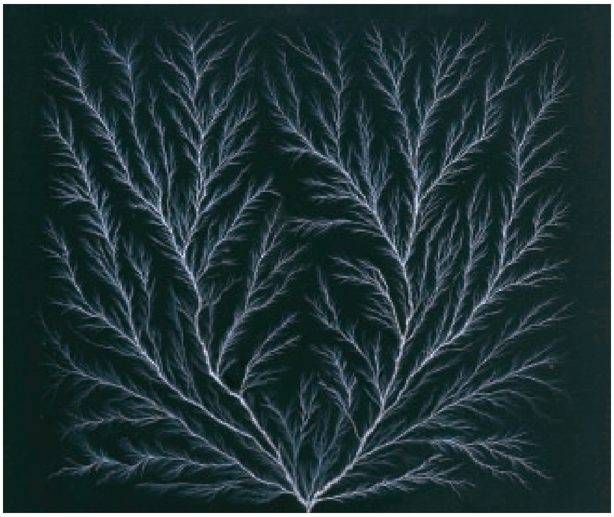


Figure 18-9
The markings caused by electrical breakdown in this material look similar to the lightning bolts produced when air undergoes electrical breakdown.

By substituting the definition of capacitance ($C = Q/\Delta V$), these alternative forms can also be shown to be valid:

$$PE_{electric} = \frac{1}{2}C(\Delta V)^2$$

$$PE_{electric} = \frac{Q^2}{2C}$$

These results apply to any capacitor. In practice, there is a limit to the maximum energy (or charge) that can be stored because electrical breakdown ultimately occurs between the plates of the capacitor for a sufficiently large potential difference. For this reason, capacitors are usually labeled with a maximum operating potential difference. Electrical breakdown in a capacitor is similar to a lightning discharge in the atmosphere. **Figure 18-9** shows a pattern created in a block of Plexiglass that has undergone electrical breakdown. This book's problems assume that all potential differences are below the maximum.

SAMPLE PROBLEM 18C

Capacitance

PROBLEM

A 3.0 μF capacitor is connected to a 12 V battery. What is the magnitude of the charge on each plate of the capacitor, and how much electrical potential energy is stored in the capacitor?

SOLUTION

Given: $C = 3.0\ \mu\text{F} = 3.0 \times 10^{-6}\ \text{F}$ $\quad \Delta V = 12\ \text{V}$

Unknown: $Q = ?$ $\quad PE_{electric} = ?$

To determine the charge, use the equation for capacitance on page 677:

$$Q = C\Delta V$$

$$Q = (3.0 \times 10^{-6}\ \text{F})(12\ \text{V}) = 36 \times 10^{-6}\ \text{C}$$

$$\boxed{Q = 36\ \mu\text{C}}$$

To determine the potential energy, use the alternative form of the equation for the potential energy of a charged capacitor shown on this page:

$$PE_{electric} = \frac{1}{2}C(\Delta V)^2$$

$$PE_{electric} = (0.5)(3.0 \times 10^{-6}\ \text{F})(12\ \text{V})^2$$

$$\boxed{PE_{electric} = 2.2 \times 10^{-4}\ \text{J}}$$

Back

PRACTICE 18C

Capacitance

1. A 4.00 μF capacitor is connected to a 12.0 V battery.
   a. What is the charge on each plate of the capacitor?
   b. If this same capacitor is connected to a 1.50 V battery, how much electrical potential energy is stored?
2. A parallel-plate capacitor has a charge of 6.0 μC when charged by a potential difference of 1.25 V.
   a. Find its capacitance.
   b. How much electrical potential energy is stored when this capacitor is connected to a 1.50 V battery?
3. A capacitor has a capacitance of 2.00 pF.
   a. What potential difference would be required to store 18.0 pC?
   b. How much charge is stored when the potential difference is 2.5 V?
4. You are asked to design a parallel-plate capacitor having a capacitance of 1.00 F and a plate separation of 1.00 mm. Calculate the required surface area of each plate. Is this a realistic size for a capacitor?

Section Review

1. Explain why two metal plates near each other will not become charged unless they are connected to a source of potential difference.
2. A parallel-plate capacitor has an area of 2.0 cm^2, and the plates are separated by 2.0 mm.
   a. What is the capacitance?
   b. How much charge does this capacitor store when connected to a 6.0 V battery?
3. A parallel-plate capacitor has a capacitance of 1.35 pF. If a 12.0 V battery is connected to this capacitor, how much electrical potential energy would it store?
4. **Physics in Action** Assume Earth and a cloud layer 800.0 m above the Earth can be treated as plates of a parallel-plate capacitor.
   a. If the cloud layer has an area of 1.00×10^6 m^2, what is the capacitance?
   b. If an electric field strength of 2.0×10^6 N/C causes the air to conduct charge (lightning), what charge can the cloud hold?

Back

CHAPTER 18
Summary

KEY TERMS

capacitance (p. 676)

electric potential (p. 670)

electrical potential energy (p. 666)

potential difference (p. 670)

KEY IDEAS

Section 18-1 Electrical potential energy
- Electrical potential energy is energy associated with a charged object due to its position relative to a source of electric force.
- Electrical potential energy is a form of mechanical energy.

Section 18-2 Potential difference
- Electric potential is electrical potential energy divided by charge.
- The electric potential at a given point in an electric field is independent of the charge at that point.
- Only differences in electric potential (potential differences) from one position to another are useful in calculations.

Section 18-3 Capacitance
- The capacitance, *C*, of an object is the amount of charge, *Q*, the object can store for a given potential difference, ΔV, as shown by the equation at right:

$$\boxed{C = \frac{Q}{\Delta V}}$$

- Capacitance depends on the shape of the capacitor, the distance between the plates, and the dielectric between the plates.
- A capacitor is a device that is used to store electrical potential energy.
- Capacitors will charge if a potential difference is applied. Once charged, a capacitor can discharge if its plates are connected by a conducting path.
- The potential energy stored in a charged capacitor depends on the charge and the final potential difference between the capacitor's two plates:

$$\boxed{PE_{electric} = \frac{1}{2}Q\Delta V}$$

Diagram symbols

Positive charge	+
Negative charge	−
Electric field vector	**E**

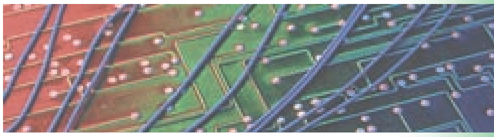
Variable symbols

Quantities		Units		Conversions
$PE_{electric}$	electrical potential energy	J	joule	$= N \bullet m$ $= kg \bullet m^2/s^2$
V	electric potential	V	volt	$= J/C$
ΔV	potential difference	V	volt	
C	capacitance	F	farad	$= C/V$

Back

CHAPTER 18

Review and Assess



ELECTRICAL POTENTIAL ENERGY

Review questions

1. Describe the motion and explain the energy conversions that are involved when a positive charge is placed in a uniform electric field. Be sure your discussion includes the following terms: *electrical potential energy, work,* and *kinetic energy.*

2. If a point charge is displaced perpendicular to a uniform electric field, which of the following expressions is likely to be equal to the change in electrical potential energy?

a. $-qEd$
b. 0
c. $-k_c\left(\dfrac{q^2}{r^2}\right)$

3. Explain why the electrical potential energy is positive for a pair of like charges but negative for a pair of unlike charges.

Practice problems

4. A point charge of 9.00×10^{-9} C is located at the origin of a coordinate system. A positive charge of 3.00×10^{-9} C is brought in from infinity to a point such that the electrical potential energy associated with the two charges is 8.09×10^{-7} J. How far apart are the charges at this time?
(See Sample Problem 18A.)

5. An electron that is initially 55 cm away from a proton is displaced to another point. If the change in the electrical potential energy as a result of this movement is 2.1×10^{-28} J, what is the final distance between the electron and the proton?
(See Sample Problem 18A.)

ELECTRIC POTENTIAL AND POTENTIAL DIFFERENCE

Review questions

6. Differentiate between electrical potential energy and electric potential.

7. Differentiate between electric potential and potential difference.

8. At what location in relationship to a point charge is the electric potential considered by convention to be zero?

Conceptual questions

9. If the electric field in some region is zero, must the electric potential in that same region also be zero? Explain your answer.

10. If a proton is released from rest in a uniform electric field, does the corresponding electric potential at the proton's changing locations increase or decrease? What about the electrical potential energy?

11. If an electron is released from rest in a uniform electric field, does the corresponding electric potential at the electron's changing locations increase or decrease? What about the electrical potential energy?

Practice problems

12. The magnitude of a uniform electric field between the two plates is about 1.7×10^6 N/C. If the distance between these plates is 1.5 cm, find the potential difference between the plates.
(See Sample Problem 18B.)

13. A force of 4.30×10^{-2} N is needed to move a charge of 56.0 μC a distance of 20.0 cm in the direction of a uniform electric field. What is the potential difference that will provide this force?
(See Sample Problem 18B.)

14. In **Figure 18-10,** find the electric potential at point *P* due to the grouping of charges at the other corners of the rectangle.
(See Sample Problem 18B.)

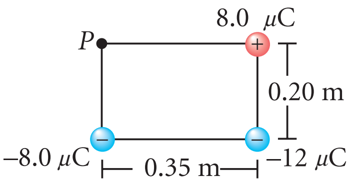


Figure 18-10

CAPACITANCE

Review questions

15. What happens to the charge on a parallel-plate capacitor if the potential difference doubles?

16. You want to increase the maximum potential difference of a parallel-plate capacitor. Describe how you can do this for a fixed plate separation.

17. Why is the Earth considered a "ground" in electric terms? Can any other object act as a ground?

Conceptual questions

18. If the potential difference across a capacitor is doubled, by what factor is the electrical potential energy stored in the capacitor multiplied?

19. Two parallel plates are uncharged. Does the set of plates have a capacitance? Explain.

20. If you were asked to design a small capacitor with high capacitance, what factors would be important in your design?

21. If the area of the plates of a parallel-plate capacitor is doubled while the spacing between the plates is halved, how is the capacitance affected?

22. A parallel-plate capacitor is charged and then disconnected from a battery. How much does the stored energy change when the plate separation is doubled?

23. Why is it dangerous to touch the terminals of a high-voltage capacitor even after the potential difference has been removed? What can be done to make the capacitor safe to handle?

24. The potential difference between a pair of oppositely charged parallel plates is 400 V.
    a. If the spacing between the plates is doubled without altering the charge on the plates, what is the new potential difference between the plates?
    b. If the plate spacing is doubled while the potential difference between the plates is kept constant, what is the ratio of the final charge on one of the plates to the original charge?

25. Two capacitors have the same potential difference across them, but one has a large capacitance and the other has a small capacitance. You would get a greater shock from touching the leads of the one with high capacitance than you would from touching the leads of the other one. From this information, explain what causes the sensation of shock.

Practice problems

26. A 12.0 V battery is connected to a 6.0 pF parallel-plate capacitor. What is the charge on each plate?
(See Sample Problem 18C.)

27. A parallel-plate capacitor has a capacitance of 0.20 μF and is to be operated at 6500 V.
    a. Calculate the charge stored.
    b. What is the electrical potential energy stored in the capacitor at the operating potential difference?

    (See Sample Problem 18C.)

28. Two devices with capacitances of 25 μF and 5.0 μF are each charged with separate 120 V power supplies. Calculate the total energy stored in the two capacitors.
(See Sample Problem 18C.)

MIXED REVIEW

29. At some distance from a point charge, the electric potential is 600.0 V and the magnitude of the electric field is 200.0 N/C. Determine the charge and the distance from the charge.

30. A circular parallel-plate capacitor with a spacing of 3.0 mm is charged to produce a uniform electric field with a strength of 3.0×10^6 N/C. What plate radius is required if the stored charge is -1.0 μC?

Back

31. Three charges are situated at three corners of a rectangle, as shown in **Figure 18-11.** How much electrical potential energy would be expended in moving the 8.0 μC charge to infinity?

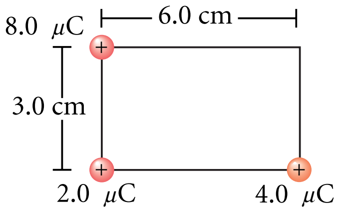


Figure 18-11

32. A 12 V battery is connected across two parallel metal plates separated by 0.30 cm. Find the magnitude of the electric field.

33. A parallel-plate capacitor has an area of 5.00 cm^2, and the plates are separated by 1.00 mm. The capacitor stores a charge of 400.0 pC.

a. What is the potential difference across the plates of the capacitor?

b. What is the magnitude of the uniform electric field in the region that is located between the plates?

34. A parallel-plate capacitor has a plate area of 175 cm^2 and a plate separation of 0.0400 mm. Determine the following:

a. the capacitance

b. the potential difference when the charge on the capacitor is 500.0 pC

35. A certain moving electron has a kinetic energy of 1.00×10^{-19} J.

a. Calculate the speed necessary for the electron to have this energy.

b. Repeat the calculation for a proton having a kinetic energy of 1.00×10^{-19} J.

36. A proton is accelerated from rest through a potential difference of 25 700 V.

a. What is the kinetic energy of this proton in joules after this acceleration?

b. What is the speed of the proton after this acceleration?

37. A proton is accelerated from rest through a potential difference of 120 V. Calculate the final speed of this proton.

38. A pair of oppositely charged parallel plates are separated by 5.33 mm. A potential difference of 600.0 V exists between the plates.

a. What is the magnitude of the electric field strength in the region that is located between the plates?

b. What is the magnitude of the force on an electron that is in the region between the plates at a point that is exactly 2.90 mm from the positive plate?

c. The electron is moved to the negative plate from an initial position 2.90 mm from the positive plate. What is the change in electrical potential energy due to the movement of this electron?

39. The three charges shown in **Figure 18-12** are located at the vertices of an isosceles triangle. Calculate the electric potential at the midpoint of the base if each one of the charges at the corners has a magnitude of 5.0×10^{-9} C.

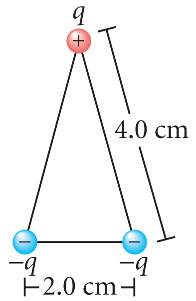


Figure 18-12

40. A charge of -3.00×10^{-9} C is at the origin of a coordinate system, and a charge of 8.00×10^{-9} C is on the x-axis at 2.00 m. At what two locations on the x-axis is the electric potential zero?
(Hint: One location is between the charges, and the other is to the left of the y-axis.)

41. A pair of oppositely charged parallel plates are separated by a distance of 5.0 cm with a potential difference of 550 V between the plates. A proton is released from rest at the positive plate at the same time that an electron is released from rest at the negative plate. Disregard any interaction between the proton and the electron.

a. How long does it take for the paths of the proton and the electron to cross?

b. How fast will each particle be going when their paths cross?

c. How much time will elapse before the proton reaches the opposite plate?

(See Appendix A for hints on solving simultaneous equations.)

42. An ion is displaced through a potential difference of 60.0 V and experiences an increase of electrical potential energy of 1.92×10^{-17} J. Calculate the charge on the ion.

43. A potential difference of 100.0 V exists across the plates of a capacitor when the charge on each plate is 400.0 μC. What is the capacitance?

44. A proton is accelerated through a potential difference of 4.5×10^6 V.

a. How much kinetic energy has the proton acquired?

b. If the proton started at rest, how fast is it moving?

45. A positron (a particle with a charge of $+e$ and a mass equal to that of an electron) that is accelerated from rest between two points at a fixed potential difference acquires a speed of 9.0×10^7 m/s. What speed is achieved by a *proton* accelerated from rest between the same two points? (Disregard relativistic effects.)

46. The speed of light is 3.00×10^8 m/s.

a. Through what potential difference would an electron starting from rest need to accelerate to achieve a speed of 60.0% of the speed of light? (Disregard relativistic effects.)

b. Repeat this calculation for a positron.

Technology & Learning

Graphing calculators

Refer to Appendix B for instructions on downloading programs for your calculator. The program "Chap18" allows you to analyze a graph of potential difference versus electrical potential energy stored in a capacitor.

The electrical potential energy stored in a charged capacitor, as you learned earlier in this chapter, is described by the following equation:

$$PE_{electric} = \frac{1}{2}C(\Delta V)^2$$

The program "Chap18" stored on your graphing calculator makes use of this equation. Once the "Chap18" program is executed, your calculator will ask for the capacitance. The graphing calculator will use the following equation to create a graph of the electrical potential energy (Y_1) versus the potential difference (X). The relationships in this equation are the same as those in the equation shown above.

$$Y_1 = CX^2/2$$

a. If the capacitance is 2.50 μF, what value should you key in on your graphing calculator?

Execute "Chap18" on the [PRGM] menu, and press [ENTER] to begin the program. Enter the value for the capacitance (shown below), and press [ENTER]. Remember to use the [(–)] key for entering negative values and [2nd] [EE] to enter exponents.

The calculator will provide a graph of the electrical potential energy versus the potential difference. (If the graph is not visible, press [WINDOW] and change the settings for the graph window, then press [GRAPH].)

Press [TRACE], and use the arrow keys to trace along the curve. The *x*-value corresponds to potential difference in volts, and the *y*-value corresponds to the potential energy in joules.

Determine the potential difference required in the following situations:

b. a 3.50 μF capacitor storing 1.20×10^{-4} J of energy

c. the same capacitor storing 3.80×10^{-4} J of energy

d. a 24.0 μF capacitor storing 4.50×10^{-4} J of energy

e. the same capacitor storing 1.80×10^{-4} J of energy

f. What is the charge on one plate of the capacitor in item (e)?

Press [2nd] [QUIT] to stop graphing. Press [ENTER] to input a new value or [CLEAR] to end the program.

Back

47. An electron moves from one plate of a capacitor to another, through a potential difference of 2200 V.

a. Find the speed with which the electron strikes the positive plate.

b. Repeat part **(a)** for a proton moving from the positive plate to the negative plate.

48. Each plate on a 3750 pF capacitor carries a charge with a magnitude of 1.75×10^{-8} C.

a. What is the potential difference across the plates when the capacitor has been fully charged?

b. If the plates are 6.50×10^{-4} m apart, what is the magnitude of the electric field between the two plates?

49. A parallel-plate capacitor is made of two circular plates, each with a diameter of 2.50×10^{-3} m. The plates of this capacitor are separated by a space of 1.40×10^{-4} m.

a. Assuming that the capacitor is operating in a vacuum and that the permittivity of a vacuum can be used, determine the capacitance for this arrangement.

b. How much charge will be stored on each plate of this capacitor when it is connected across a potential difference of 0.12 V?

c. What is the electrical potential energy stored in this capacitor when it is fully charged by the potential difference of 0.12 V?

d. What is the potential difference between a point midway between the plates and a point that is 1.10×10^{-4} m from one of the plates?

e. If the potential difference of 0.12 V is removed from the circuit and if the circuit is allowed to discharge until the charge on the plates has decreased to 70.7 percent of its fully charged value, what will the potential difference across the capacitor be?

Alternative Assessment

Performance assessment

1. If the electric potential in a certain region of space is zero, can you infer that there is no electric charge in that area? Come up with examples of sets of charges that support your inference, and be prepared to defend your conclusion in a class discussion.

2. Imagine that you are assisting nuclear scientists who need to accelerate electrons between electrically charged plates. Design and sketch a piece of equipment that could accelerate electrons to 10^7 m/s. What should the potential difference be between the plates? How would protons move inside this device? What would you change in order to accelerate the electrons to 100 m/s?

Portfolio projects

3. Tantalum is an element widely used in electrolytic capacitors. Research tantulum and its properties. Where on Earth is it found? In what form is it found? How expensive is it? Present your findings to the class in the form of a report, poster, or computer presentation.

4. Investigate how the shape of equally charged objects affects the potential around them. Examine the case of a point charge of 1 C, a hollow conducting sphere with a charge of 1 C, and a 1 m × 1 m square plate with a charge of 1 C. Find the electric potential at increasing distances from 0.1 m to 10 m along a line through the center of each charge. Draw graphs of the electric potential versus the distance from the charged object, and compare them.

5. Research what types of capacitors are used in different electrical and electronic devices. If possible, obtain old radios, telephones, or other electronic instruments that you can take apart. Find the capacitors, and describe them. Complete this research by visiting electronics stores or by examining catalogs of electrical and electronic equipment. Do the capacitors that are the largest in size have the largest capacitance values? Can you find out what substances are used to make these capacitors? Compile the class findings in a poster or an exhibit about these capacitors, and indicate their relative sizes, structures, capacitances, and uses.

Back

CHAPTER 18
Laboratory Exercise

OBJECTIVES

- Explore the relationship between electrical energy and energy transferred by heat.
- Calculate the energy stored in a charged capacitor.

MATERIALS LIST

- ✔ 1-farad capacitor
- ✔ 10 Ω resistor
- ✔ insulated connecting wire
- ✔ low-calorie calorimeter with thermometer support
- ✔ momentary contact switch
- ✔ multimeter or dc voltmeter
- ✔ plastic electrical tape
- ✔ power supply
- ✔ stopwatch
- ✔ thermometer

CAPACITANCE AND ELECTRICAL ENERGY

When a capacitor is charged, it stores electrical potential energy, which can be measured by a change in temperature. In this experiment, you will charge a capacitor, then discharge it through a wire coil inside a special calorimeter. You will use the initial and final temperatures of the calorimeter to calculate the amount of energy transferred from the capacitor to the wire.

SAFETY

- Use a hot mitt to handle resistors, light sources, and other equipment that may be hot. Allow all equipment to cool before storing it.
- Never put broken glass or ceramics in a regular waste container. Use a dustpan, brush, and heavy gloves to carefully pick up broken pieces, and dispose of them in a container specifically provided for this purpose.

PREPARATION

1. Read the entire lab, and plan the steps you will take.
2. Prepare a data table in your lab notebook with six columns and five rows. In the first row, label the columns *Trial, Mass of calorimeter (kg),* T_i *(°C),* T_{max} *(°C),* ΔV_c *(V),* and $C_{capacitor}$ *(F)*. In the first column, label the second through fifth rows *1, 2, 3,* and *4.*

PROCEDURE

Charging the capacitor

3. Record the value of the capacitor in farads as $C_{capacitor}$.
4. Set up the apparatus as shown in **Figure 18-13.** Place the switch in front of you so that the switch moves from right to left. Using leads with alligator clips on both ends, connect the low-calorie calorimeter to the pins on the right side of the switch, and connect the capacitor to the center pins of the switch. Using leads with alligator clips on one end and banana terminals on the other, connect the resistor in series with the power supply and the pins on the left side of the switch. Connect the voltage meter to measure the potential difference across the capacitor. ***Do not close the switch until your teacher approves your circuit.***

5. Place the bulb end of the thermometer in the calorimeter. If necessary, carefully wrap one or two turns of electrical tape around the bulb to ensure a good fit. Place the other end of the thermometer in a support so that the thermometer is easy to read. Record the initial temperature of the calorimeter in your data table as T_i. ***Do not close the switch.***

6. When your teacher has approved your circuit, turn on the power supply and close the switch to the left in order to charge the capacitor. While the capacitor is charging, watch the voltage meter. When the potential difference across the capacitor remains constant for 30 s, record the value.

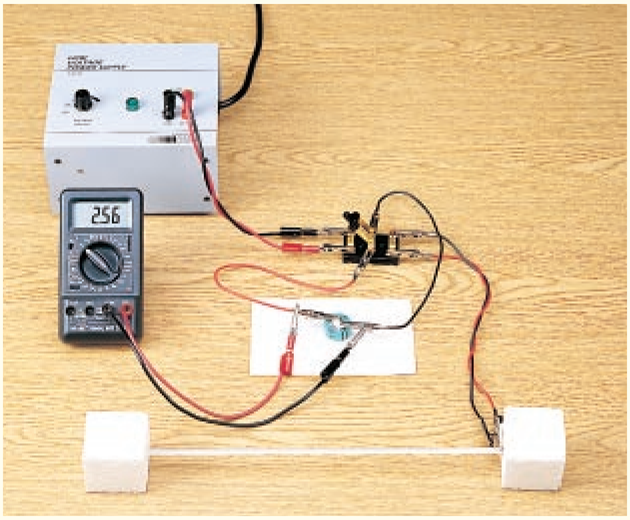


Figure 18-13
Step 4: Place the switch in front of you so that it moves from right to left. Check all connections carefully.
Step 5: Carefully place the bulb end of the thermometer in the calorimeter. Support the other end of the thermometer by placing it in a support, as shown.
Step 7: While the capacitor is discharging, read and record the temperature of the calorimeter at 5.0 s intervals.

Discharging the capacitor

7. Close the switch to the right to discharge the capacitor so that the current will be in the wire inside the calorimeter. Read the temperature of the calorimeter to the nearest 0.1°C at 5.0 s intervals until five consecutive readings are the same. Record the maximum temperature reached in your data table.

8. Repeat the procedure for three more trials. ***Do not close the switch until your teacher approves your circuit.*** Record all data for all trials.

9. Clean up your work area. Put equipment away safely so that it is ready to be used again.

ANALYSIS AND INTERPRETATION

Calculations and data analysis

1. **Organizing data** For each trial recorded in your data table, perform the following calculations.
   a. Calculate the temperature change of the calorimeter.
   b. Your teacher will give you the value for the calibration constant of the calorimeter in J/°C. With that value, calculate the energy transferred to the calorimeter as heat.

2. **Organizing information** Use the equation $PE_{electric} = \frac{1}{2}C(\Delta V)^2$ to calculate the energy stored in the capacitor for each trial.

Conclusions

3. **Evaluating results** For each trial, compare the energy transferred to the calorimeter as heat to the energy stored in the capacitor. Based on your observations, is energy conserved in this experiment? Explain.

Back

Are Electric Cars an Answer to Pollution?

In 1909, more than 50 percent of the automobiles in the United States were propelled by electric motors. These cars could go only a few miles before their batteries needed recharging, but they were more reliable than gasoline-powered cars, and starting them did not require hand cranking. Electric cars worked well for most in-city use, but as more roads were paved and as more people wanted to travel farther, electric cars were abandoned.

The return of electric cars

As industry spread and the number of cars on the road increased, the air in North America became more polluted and people searched for ways to reduce the pollution and its harmful effects on human health. In recent decades, federal and state laws have required industries and businesses–from steelmakers to dry cleaners–to limit polluting emissions. Although overall air quality has improved due to these regulations, pollution within many cities remains a serious problem, primarily because of emissions from motor-powered vehicles that use gasoline-burning internal combustion engines, or ICEs.

Gasoline-fueled cars emit nitrogen oxides, carbon monoxide, and unburned hydrocarbons—all of which, along with ozone, make up a major part of urban air pollution. In addition, ICEs give off large quantities of carbon dioxide, which contributes to Earth's greenhouse effect. So, because they emit no polluting exhaust fumes, people are interested once again in electric vehicles.

Modern electric vehicles

An electric vehicle, or EV, is powered by an electric motor with current supplied by an array of batteries. To recharge the batteries, the owner plugs the car into a recharging unit at home. The charging energy comes from the same electric-generating plants that produce household current. Besides producing no polluting exhaust, the main advantages of EVs are that they need no hydrocarbon fuel, they are quiet, and, because there are fewer moving parts to wear out, they are likely to last longer than cars with ICEs.

However, even EV proponents and manufacturers realize that EVs available now and in the near future have some major drawbacks. EVs can travel only about 65 km to 160 km before needing a recharge, which is not far enough for intercity travel or family trips. Also, EVs presently cost between $30,000 and $75,000, prices that are unacceptable to most consumers, especially when they consider the cars' limited range. Another problem is that the lead-acid batteries used in EVs, which cost about $3000, have to be replaced every two to three years.

The question of pollution

Many people wonder whether replacement of ICE vehicles by EVs will reduce air pollution and greenhouse gases or will increase the problem. After all, in charging a vehicle, the owner would be using electricity supplied by a power plant, which in its operation most likely

Back

causes air pollution. In some regions, such as southern California and the Pacific Northwest, abundant electrical energy is available from relatively nonpolluting hydroelectric, nuclear, and natural-gas-burning power plants. The need to charge large numbers of EVs is unlikely to increase pollution at these sites.

On the other hand, 55 percent of plants in the United States are powered by burning coal. Power plants will have to increase output by burning more coal, and new plants may have to be built. One scientist estimates that complete conversion to EVs would double the output of sulfur dioxide, a cause of acid rain, from coal-burning plants.

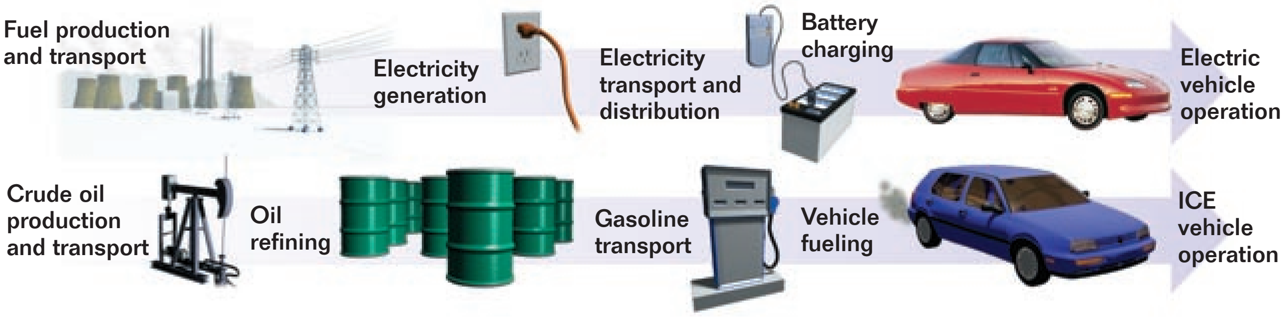
Supporters of EVs say that most people would recharge their vehicles overnight when plants are operating their capacity. EV proponents also have estimated that 20 million EVs could be supported in the United States without any new power plants. In addition, they claim that burning coal to generate electric current to power an EV is up to twice as efficient as burning gasoline to power a car.

To settle this question, the U.S. Department of Energy has assigned Argonne National Laboratories to perform a Total Energy Cycle Assessment comparing the energy efficiency of EVs with that of vehicles that run on gasoline. Technicians will consider every step, from producing fuel to using the energy to move a car. In addition, they will keep track of all emissions, leftover material, and all activities involved in using and maintaining the vehicles. The results of this study should provide answers that will shape the destiny of electric vehicles.

internetconnect

SCILINKS NSTA

TOPIC: Electric vehicles
GO TO: www.scilinks.org
***sci*LINKS CODE:** HF2185



Researching the Issue

1. If the Argonne study reveals that gasoline-powered cars are more energy-efficient than EVs, do you think that EVs should be discontinued? Account for your opinion.

2. The limited range of EVs is one of their biggest drawbacks. Do research to find out about hybrid electric vehicles, or HEVs. Describe how they operate and explain the differences between series and parallel HEVs. How might these vehicles overcome the range limitations of EVs?

3. The state of California has mandated that by the year 2003 at least 10 percent of the vehicles for sale in the state must be zero-emission vehicles, and EVs are the only vehicles that meet that requirement. Other states have passed similar laws. Because EVs are so expensive, the federal and state governments are offering subsidies and tax credits to people who will buy them. Hold a discussion or debate on the question, "Should the government spend taxpayers' money to subsidize the purchase of nonpolluting vehicles that people might not otherwise buy?"