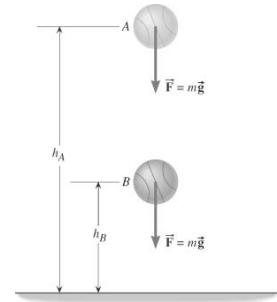


Chapter 19

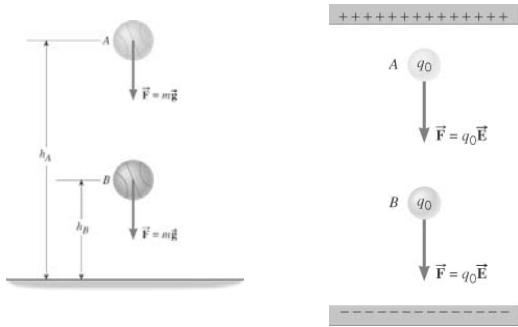
Electric Fields and Electric Forces

19.1 Potential Energy

$$W_{AB} = mgh_A - mgh_B = \text{GPE}_A - \text{GPE}_B$$

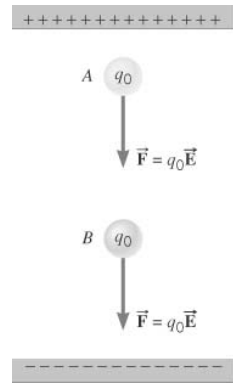


19.1 Potential Energy



19.1 Potential Energy

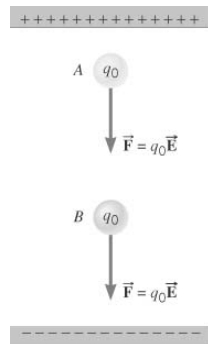
$$W_{AB} = \text{EPE}_A - \text{EPE}_B$$



19.2 The Electric Potential Difference

$$\frac{W_{AB}}{q_o} = \frac{\text{EPE}_A}{q_o} - \frac{\text{EPE}_B}{q_o}$$

The potential energy per unit charge is called the electric potential.



19.2 The Electric Potential Difference

DEFINITION OF ELECTRIC POTENTIAL

The electric potential at a given point is the electric potential energy of a small test charge divided by the charge itself.

$$V = \frac{\text{EPE}}{q_o}$$

SI Unit of Electric Potential: joule/coulomb = volt (V)

$$V_B - V_A = \frac{\text{EPE}_B}{q_o} - \frac{\text{EPE}_A}{q_o} = \frac{-W_{AB}}{q_o}$$

$$\Delta V = \frac{\Delta(\text{EPE})}{q_o} = \frac{-W_{AB}}{q_o}$$

19.2 The Electric Potential Difference

Example 1 Work, Potential Energy, and Electric Potential

The work done by the electric force as the test charge ($+2.0 \times 10^{-6} \text{C}$) moves from A to B is $+5.0 \times 10^{-5} \text{J}$.

(a) Find the difference in EPE between these points.

(b) Determine the potential difference between these points.

$$W_{AB} = \text{EPE}_A - \text{EPE}_B$$

$$V_B - V_A = \frac{\text{EPE}_B}{q_o} - \frac{\text{EPE}_A}{q_o} = \frac{-W_{AB}}{q_o}$$

19.2 The Electric Potential Difference

(a) $W_{AB} = \text{EPE}_A - \text{EPE}_B$

$$\text{EPE}_B - \text{EPE}_A = -W_{AB} = -5.0 \times 10^{-5} \text{J}$$

(b)

$$V_B - V_A = \frac{-W_{AB}}{q_o} = \frac{-5.0 \times 10^{-5} \text{J}}{2.0 \times 10^{-6} \text{C}} = -25 \text{V}$$

19.2 The Electric Potential Difference

Conceptual Example 2 The Accelerations of Positive and Negative Charges

A positive test charge is released from A and accelerates towards B. Upon reaching B, the test charge continues to accelerate toward C. Assuming that only motion along the line is possible, what will a negative test charge do when released from rest at B?

19.2 The Electric Potential Difference

A positive charge accelerates from a region of higher electric potential toward a region of lower electric potential.

A negative charge accelerates from a region of lower potential toward a region of higher potential.

19.2 The Electric Potential Difference

We now include electric potential energy EPE as part of the total energy that an object can have:

$$E = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + mgh + \frac{1}{2}kx^2 + \text{EPE}$$

One electron volt is the magnitude of the amount by which the potential energy of an electron changes when the electron moves through a potential difference of one volt.

$$1 \text{eV} = 1.60 \times 10^{-19} \text{J}$$

19.2 The Electric Potential Difference

Example 4 The Conservation of Energy

A particle has a mass of $1.8 \times 10^{-5} \text{kg}$ and a charge of $+3.0 \times 10^{-5} \text{C}$. It is released from point A and accelerates horizontally until it reaches point B. The only force acting on the particle is the electric force, and the electric potential at A is 25V greater than at C. (a) What is the speed of the particle at point B? (b) If the same particle had a negative charge and were released from point B, what would be its speed at A?

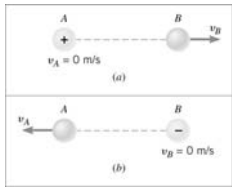
19.2 The Electric Potential Difference

$$\frac{1}{2}mv_B^2 + EPE_B = \frac{1}{2}mv_A^2 + EPE_A$$

$$\Downarrow$$

$$\frac{1}{2}mv_B^2 = \frac{1}{2}mv_A^2 + EPE_A - EPE_B$$

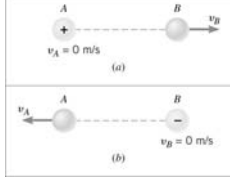
$$\Downarrow$$

$$\frac{1}{2}mv_B^2 = \frac{1}{2}mv_A^2 + q_o(V_A - V_B)$$


19.2 The Electric Potential Difference

(a) $\frac{1}{2}mv_B^2 = q_o(V_A - V_B)$

$$v_B = \sqrt{2q_o(V_A - V_B)/m}$$

$$= \sqrt{2(3.0 \times 10^{-5} \text{ C})(25 \text{ V})/(1.8 \times 10^{-3} \text{ kg})} = 9.1 \text{ m/s}$$


(a) $v_A = \sqrt{-2q_o(V_A - V_B)/m}$

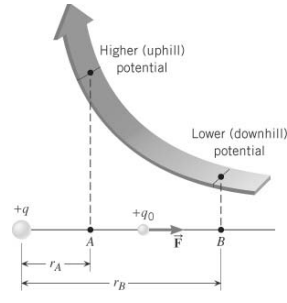
$$= \sqrt{-2(-3.0 \times 10^{-5} \text{ C})(25 \text{ V})/(1.8 \times 10^{-3} \text{ kg})} = 9.1 \text{ m/s}$$

19.3 The Electric Potential Difference Created by Point Charges

$$W_{AB} = \frac{kq q_o}{r_A} - \frac{kq q_o}{r_B}$$

$$V_B - V_A = \frac{-W_{AB}}{q_o} = \frac{kq}{r_A} - \frac{kq}{r_B}$$

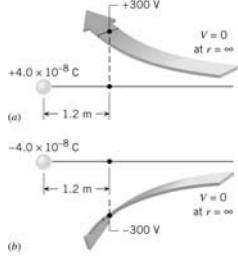
Potential of a point charge $V = \frac{kq}{r}$



19.3 The Electric Potential Difference Created by Point Charges

Example 5 The Potential of a Point Charge

Using a zero reference potential at infinity, determine the amount by which a point charge of $4.0 \times 10^{-8} \text{ C}$ alters the electric potential at a spot 1.2 m away when the charge is (a) positive and (b) negative.

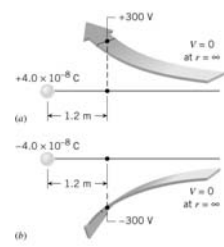


19.3 The Electric Potential Difference Created by Point Charges

(a)

$$V = \frac{kq}{r} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(+4.0 \times 10^{-8} \text{ C})}{1.2 \text{ m}} = +300 \text{ V}$$

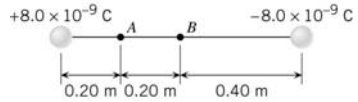
(b)

$$V = -300 \text{ V}$$


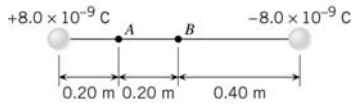
19.3 The Electric Potential Difference Created by Point Charges

Example 6 The Total Electric Potential

At locations A and B, find the total electric potential.



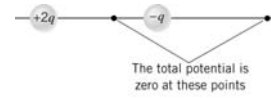
19.3 The Electric Potential Difference Created by Point Charges



$$V_A = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(+8.0 \times 10^{-9} \text{ C})}{0.20 \text{ m}} + \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(-8.0 \times 10^{-9} \text{ C})}{0.60 \text{ m}} = +240 \text{ V}$$

$$V_B = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(+8.0 \times 10^{-9} \text{ C})}{0.40 \text{ m}} + \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(-8.0 \times 10^{-9} \text{ C})}{0.40 \text{ m}} = 0 \text{ V}$$

19.3 The Electric Potential Difference Created by Point Charges



Conceptual Example 7 Where is the Potential Zero?

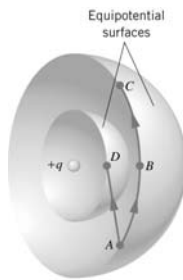
Two point charges are fixed in place. The positive charge is $+2q$ and the negative charge is $-q$. On the line that passes through the charges, how many places are there at which the total potential is zero?

19.4 Equipotential Surfaces and Their Relation to the Electric Field

An **equipotential surface** is a surface on which the electric potential is the same everywhere.

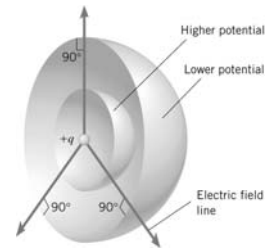
$$V = \frac{kq}{r}$$

The net electric force does no work on a charge as it moves on an equipotential surface.

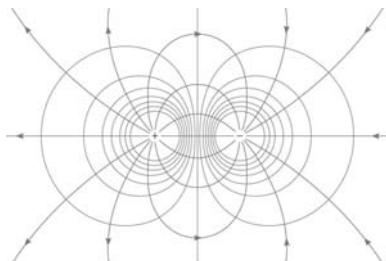


19.4 Equipotential Surfaces and Their Relation to the Electric Field

The electric field created by any charge or group of charges is everywhere perpendicular to the associated equipotential surfaces and points in the direction of decreasing potential.

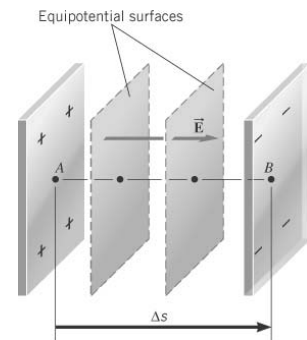


19.4 Equipotential Surfaces and Their Relation to the Electric Field



19.4 Equipotential Surfaces and Their Relation to the Electric Field

$$E = -\frac{\Delta V}{\Delta s}$$



19.4 Equipotential Surfaces and Their Relation to the Electric Field

Example 9 The Electric Field and Potential Are Related

The plates of the capacitor are separated by a distance of 0.032 m, and the potential difference between them is $V_B - V_A = -64\text{V}$. Between the two equipotential surfaces shown in color, there is a potential difference of -3.0V . Find the spacing between the two colored surfaces.

19.4 Equipotential Surfaces and Their Relation to the Electric Field

$$E = -\frac{\Delta V}{\Delta s} = \frac{-64\text{ V}}{0.032\text{ m}} = 2.0 \times 10^3\text{ V/m}$$

$$\Delta s = -\frac{\Delta V}{E} = -\frac{-3.0\text{ V}}{2.0 \times 10^3\text{ V/m}} = 1.5 \times 10^{-3}\text{ m}$$

19.5 Capacitors and Dielectrics

A parallel plate capacitor consists of two metal plates, one carrying charge $+q$ and the other carrying charge $-q$.

It is common to fill the region between the plates with an electrically insulating substance called a **dielectric**.

19.5 Capacitors and Dielectrics

THE RELATION BETWEEN CHARGE AND POTENTIAL DIFFERENCE FOR A CAPACITOR

The magnitude of the charge in each plate of the capacitor is directly proportional to the magnitude of the potential difference between the plates.

$$q = CV$$

The capacitance C is the proportionality constant.

SI Unit of Capacitance: coulomb/volt = farad (F)

19.5 Capacitors and Dielectrics

THE DIELECTRIC CONSTANT

If a dielectric is inserted between the plates of a capacitor, the capacitance can increase markedly.

$$\text{Dielectric constant} \quad \kappa = \frac{E_o}{E}$$

19.5 Capacitors and Dielectrics

Table 19.1 Dielectric Constants of Some Common Substances^a

Substance	Dielectric Constant, κ
Vacuum	1
Air	1.000 54
Teflon	2.1
Benzene	2.28
Paper (royal gray)	3.3
Ruby mica	5.4
Neoprene rubber	6.7
Methyl alcohol	33.6
Water	80.4

^aNear room temperature.

19.5 Capacitors and Dielectrics

THE CAPACITANCE OF A PARALLEL PLATE CAPACITOR

$$E_o = q/(\epsilon_o A)$$

$$E = \frac{E_o}{\kappa} = \frac{V}{d}$$

$$q = \left(\frac{\kappa \epsilon_o A}{d} \right) V$$

Parallel plate capacitor filled with a dielectric $C = \frac{\kappa \epsilon_o A}{d}$

19.5 Capacitors and Dielectrics

Conceptual Example 11 The Effect of a Dielectric When a Capacitor Has a Constant Charge

An empty capacitor is connected to a battery and charged up. The capacitor is then disconnected from the battery, and a slab of dielectric material is inserted between the plates. Does the voltage across the plates increase, remain the same, or decrease?

19.5 Capacitors and Dielectrics

Example 12 A Computer Keyboard

One common kind of computer keyboard is based on the idea of capacitance. Each key is mounted on one end of a plunger, the other end being attached to a movable metal plate. The movable plate and the fixed plate form a capacitor. When the key is pressed, the capacitance increases. The change in capacitance is detected, thereby recognizing the key which has been pressed.

The separation between the plates is 5.00 mm, but is reduced to 0.150 mm when a key is pressed. The plate area is $9.50 \times 10^{-5} \text{ m}^2$ and the capacitor is filled with a material whose dielectric constant is 3.50.

Determine the change in capacitance detected by the computer.

19.5 Capacitors and Dielectrics

$$C = \frac{\kappa \epsilon_o A}{d} = \frac{(3.50)(8.85 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2))(9.50 \times 10^{-5} \text{ m}^2)}{0.150 \times 10^{-3} \text{ m}} = 19.6 \times 10^{-12} \text{ F}$$

$$C = \frac{\kappa \epsilon_o A}{d} = \frac{(3.50)(8.85 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2))(9.50 \times 10^{-5} \text{ m}^2)}{5.00 \times 10^{-3} \text{ m}} = 0.589 \times 10^{-12} \text{ F}$$

$$\Delta C = 19.0 \times 10^{-12} \text{ F}$$

19.5 Capacitors and Dielectrics

ENERGY STORAGE IN A CAPACITOR

$$\text{Energy} = \frac{1}{2} CV^2$$

$$\text{Energy} = \frac{1}{2} \left(\frac{\kappa \epsilon_o A}{d} \right) (Ed)^2$$

Volume = Ad

$$\text{Energy density} = \frac{\text{Energy}}{\text{Volume}} = \frac{1}{2} \kappa \epsilon_o E^2$$
