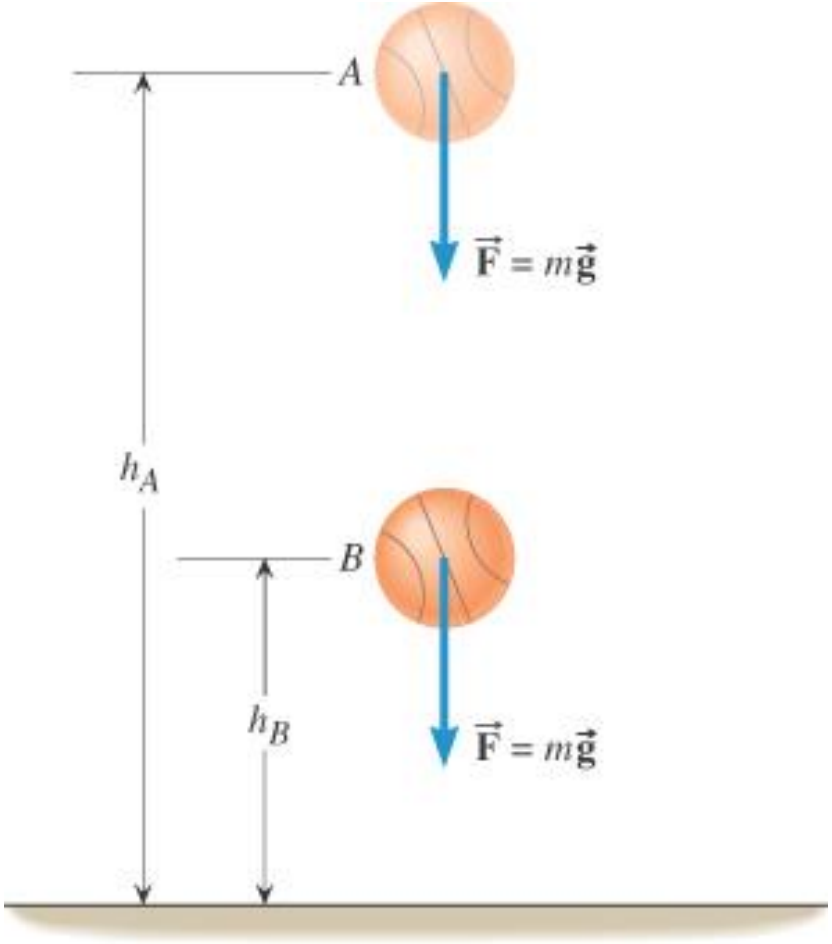
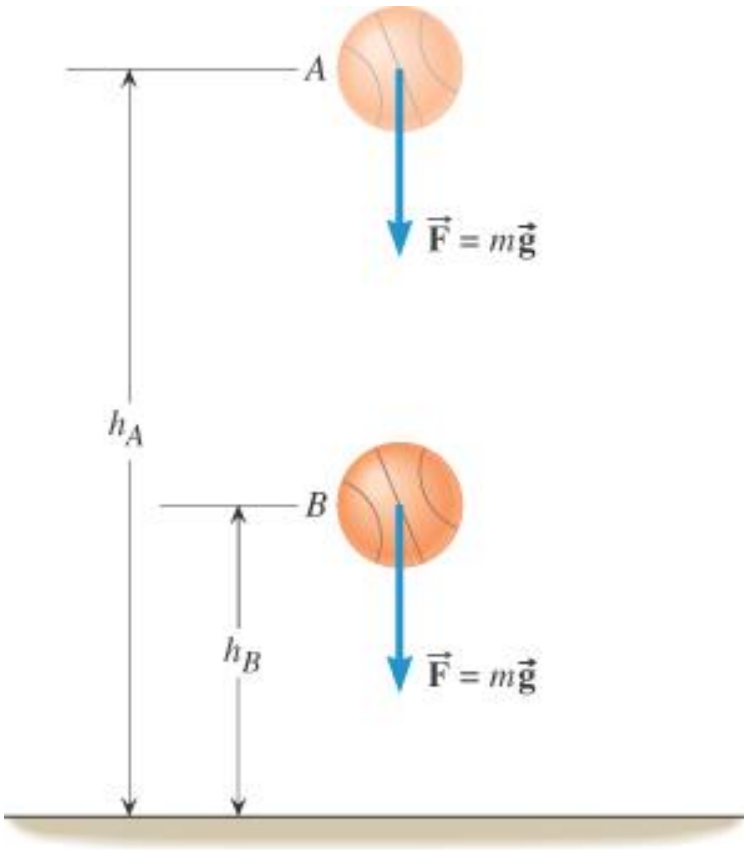
Chapter 19

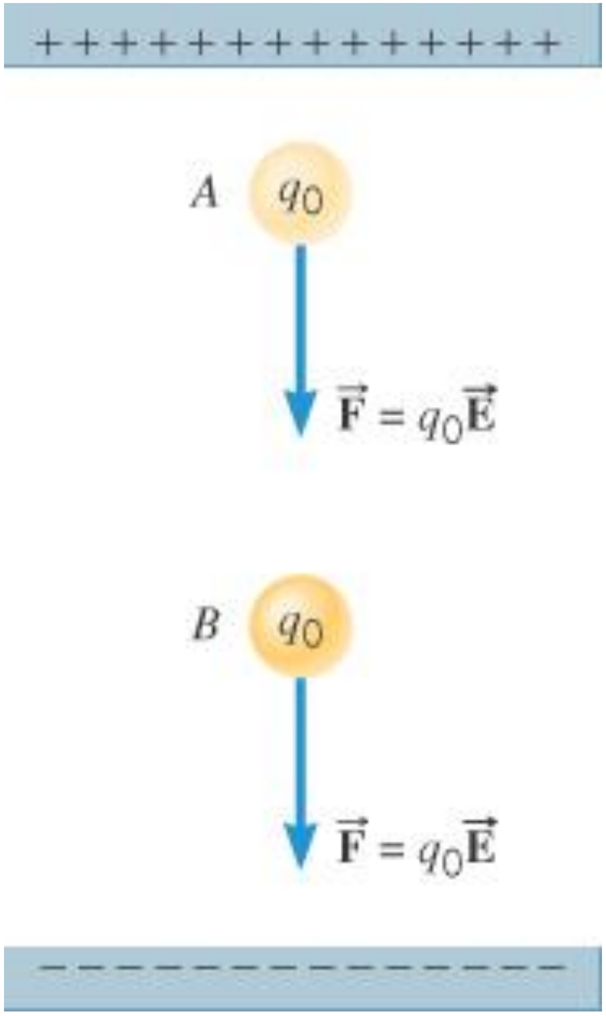
Electric Potential Energy and the Electric Potential

19.1 Potential Energy

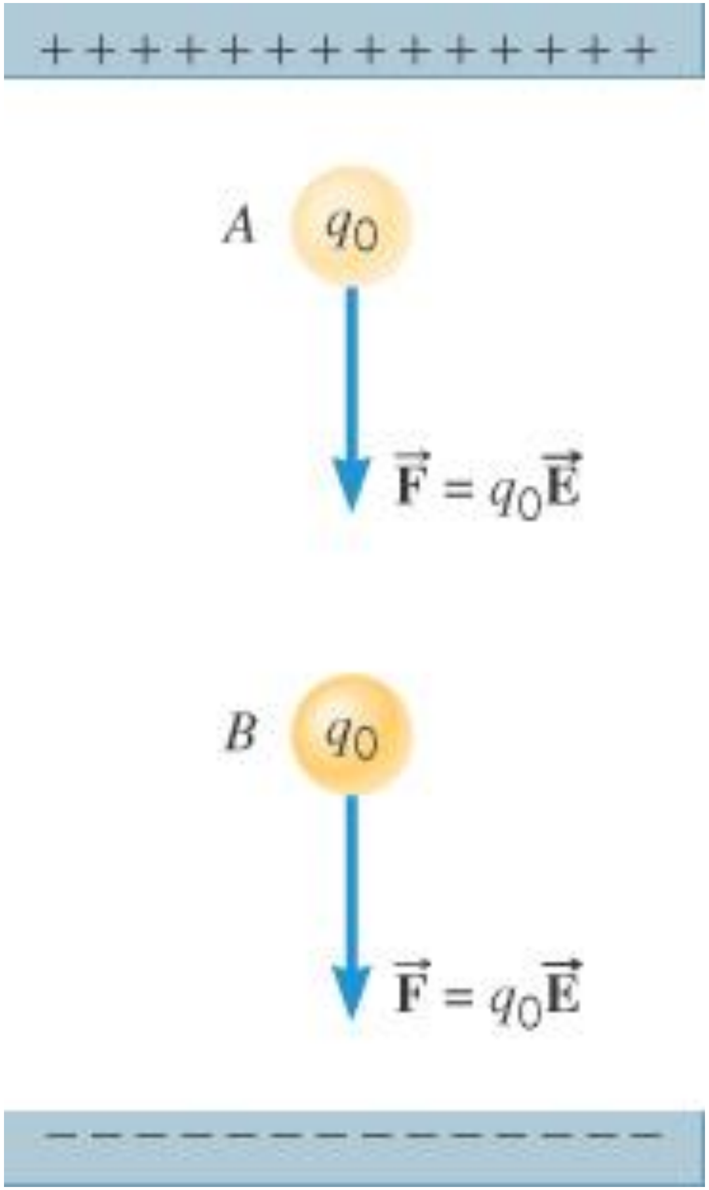
$$W_{AB} = mgh_A - mgh_B = \mathrm{GPE}_A - \mathrm{GPE}_B$$




A
B
h_A
h_B
$\vec{F} = m\vec{g}$
$\vec{F} = m\vec{g}$

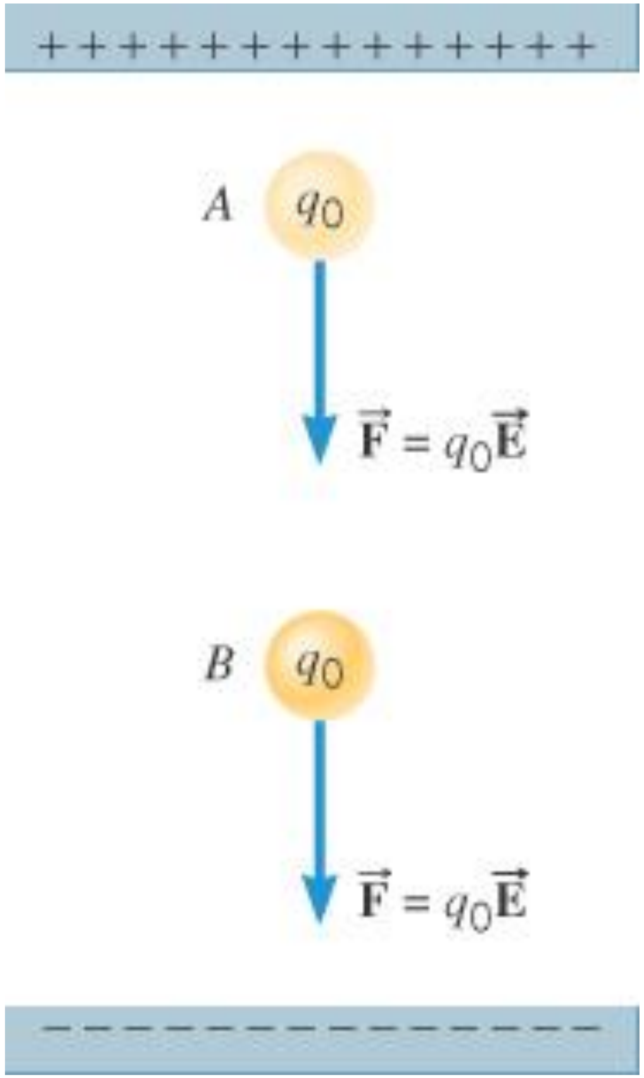

+++++++++++++++
A
q_0
$\vec{F} = q_0\vec{E}$
B
q_0
$\vec{F} = q_0\vec{E}$
–––––––––––––––

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



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

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



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:

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

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

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

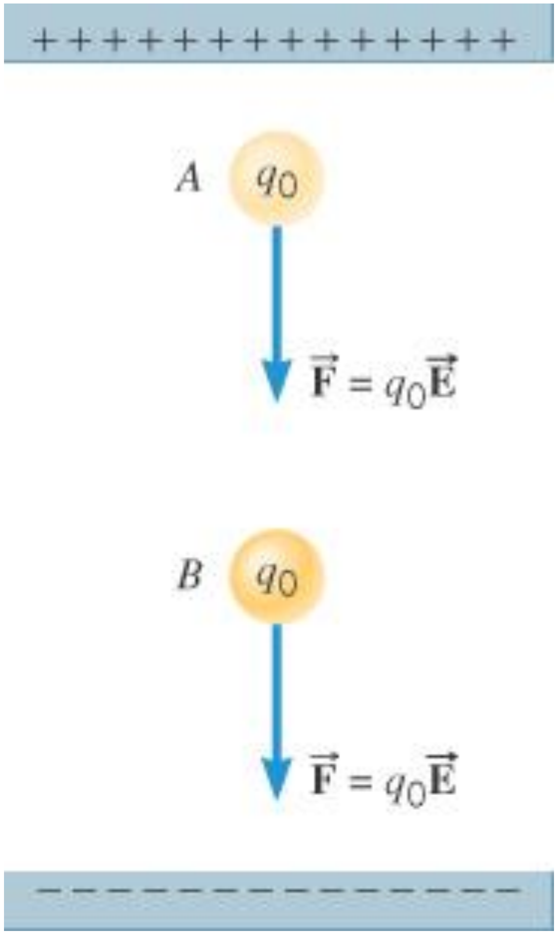
$$\Delta V = \frac{\Delta(\mathrm{EPE})}{q_o} = \frac{-W_{AB}}{q_o}$$

Example 1 **Work, Potential Energy, and Electric Potential**

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

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

(b) Determine the potential difference between these points.



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

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

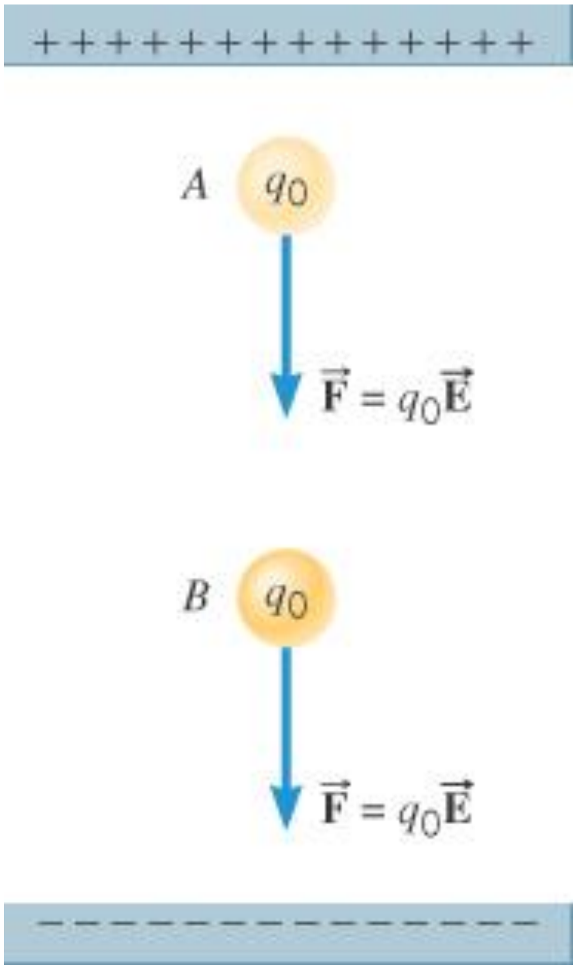
19.2 The Electric Potential Difference

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

$$\text{EPE}_B - \text{EPE}_A = -W_{AB} = -5.0\times10^{-5}\,\text{J}$$

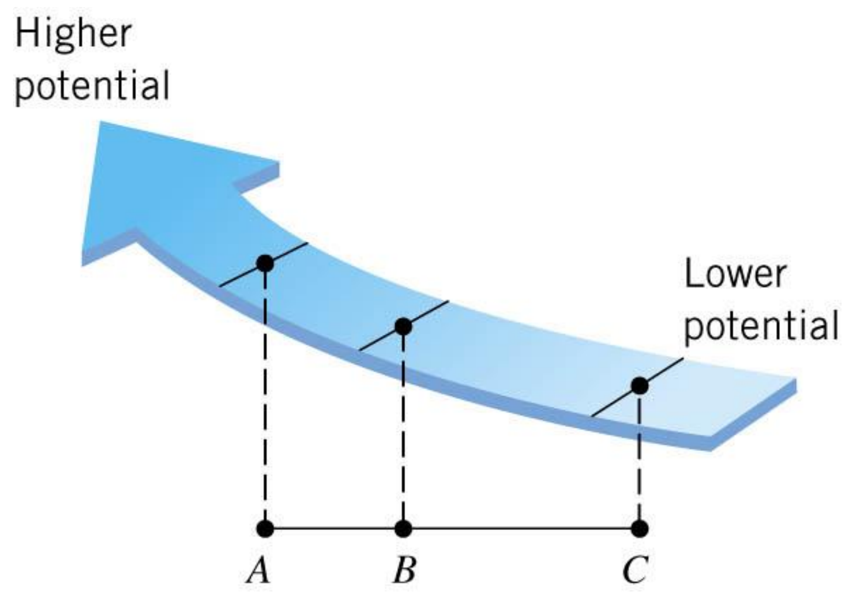
(b)

$$V_B - V_A = \frac{-W_{AB}}{q_o} = \frac{-5.0\times10^{-5}\,\text{J}}{2.0\times10^{-6}\,\text{C}} = -25\,\text{V}$$



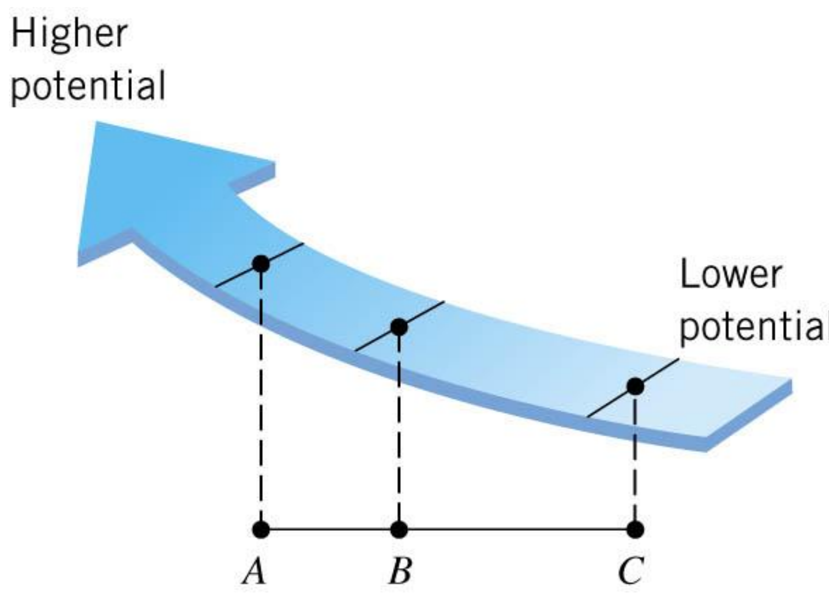
Conceptual Example 2 The Accelerations of Positive and Negative Charges

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?



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:

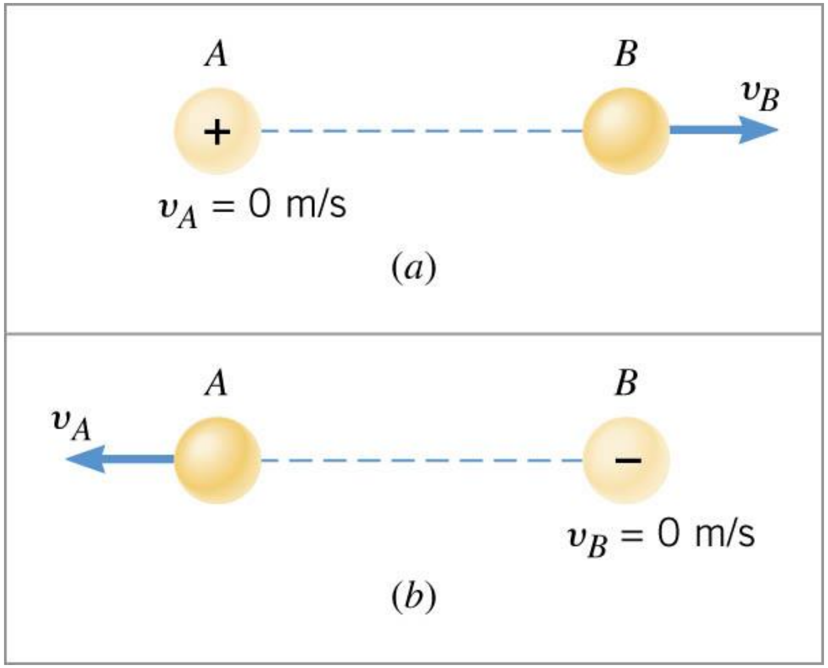
$$E = \tfrac{1}{2}mv^2 + \tfrac{1}{2}I\omega^2 + mgh + \tfrac{1}{2}kx^2 + EPE$$

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.

$$1\,\mathrm{eV} = 1.60\times 10^{-19}\,\mathrm{V}$$

Example 4 The Conservation of Energy

A particle has a mass of $1.8\text{x}10^{-5}$kg and a charge of $+3.0\text{x}10^{-5}$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

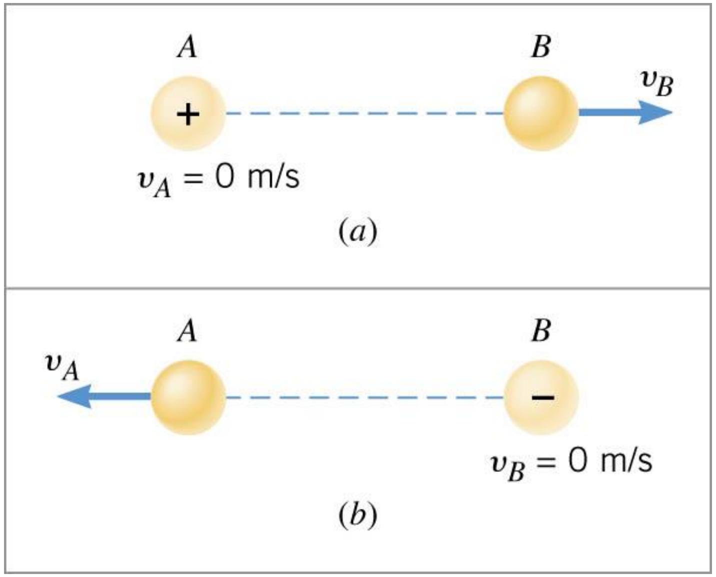
$$\tfrac{1}{2}mv_B^2 + EPE_B = \tfrac{1}{2}mv_A^2 + EPE_A$$

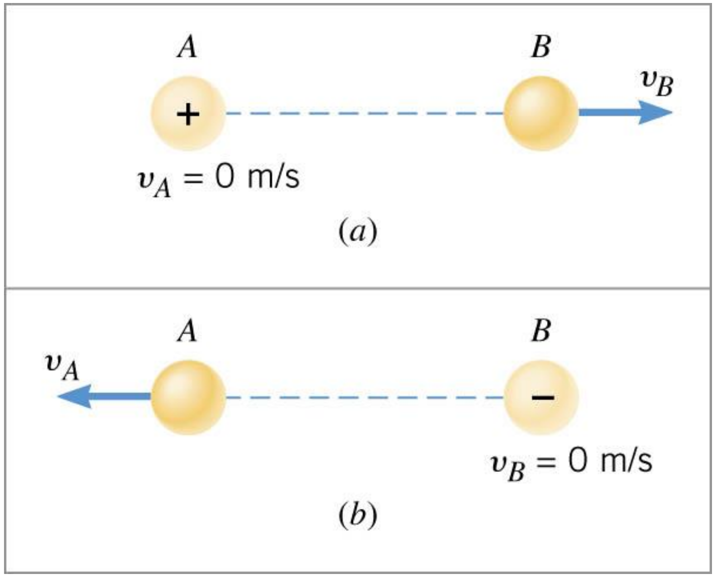
$$\Downarrow$$

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

$$\Downarrow$$

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





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

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

$$= \sqrt{2(3.0\times10^{-5}\,\mathrm{C})(25\,\mathrm{V})/(1.8\times10^{-5}\,\mathrm{kg})} = 9.1\,\mathrm{m/s}$$

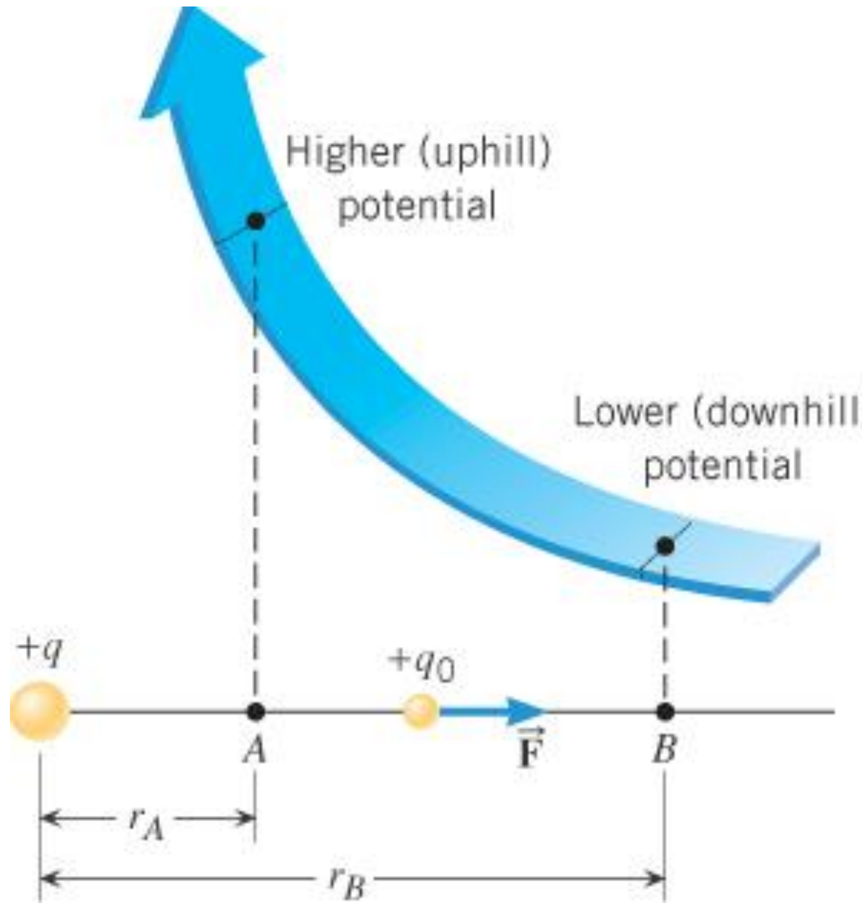
(a) $$v_A = \sqrt{-2q_o(V_A - V_B)/m}$$

$$= \sqrt{-2(-3.0\times10^{-5}\,\mathrm{C})(25\,\mathrm{V})/(1.8\times10^{-5}\,\mathrm{kg})} = 9.1\,\mathrm{m/s}$$

19.3 The Electric Potential Difference Created by Point Charges

$$W_{AB} = \frac{kqq_o}{r_A} - \frac{kqq_o}{r_B}$$

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

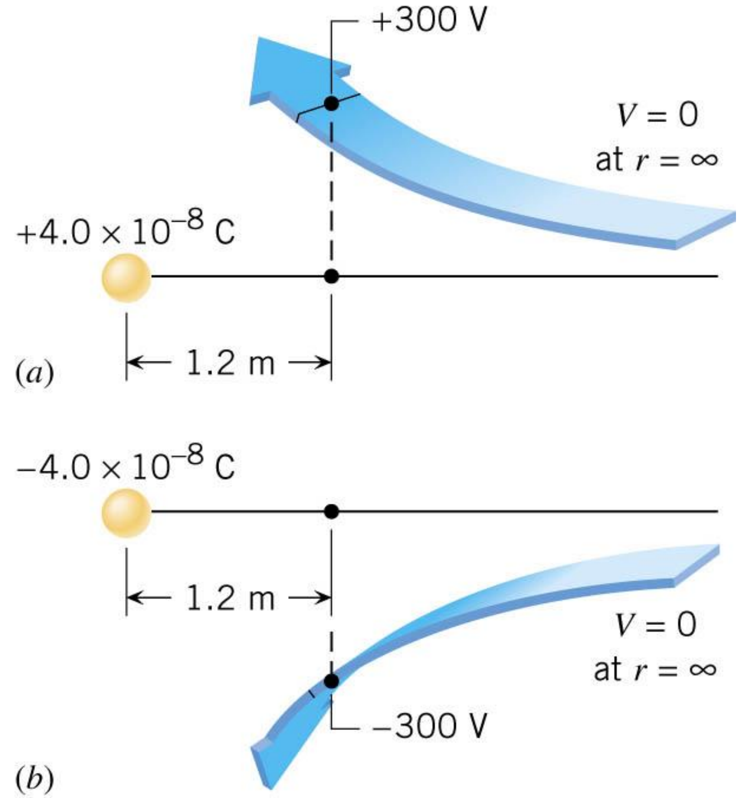


Potential of a point charge

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

Example 5 The Potential of a Point Charge

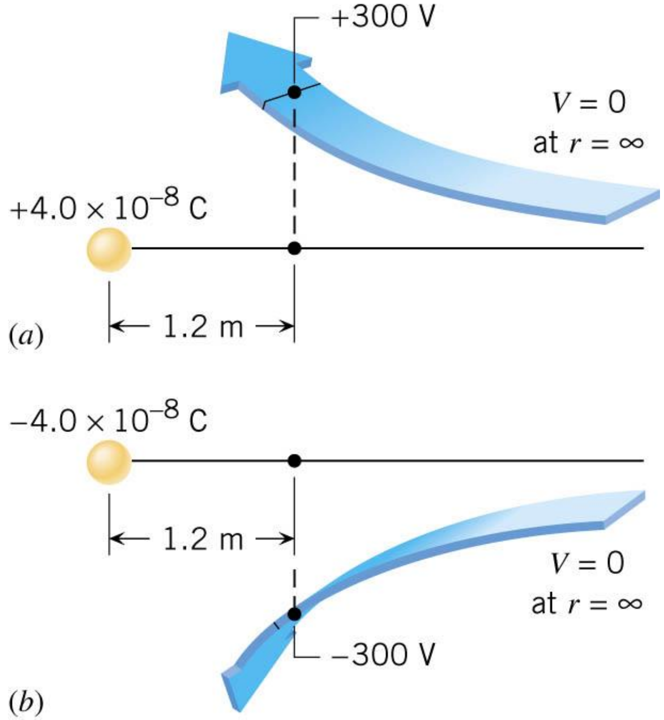
Using a zero reference potential at infinity, determine the amount by which a point charge of $4.0\text{x}10^{-8}$C alters the electric potential at a spot 1.2m away when the charge is
(a) positive and (b) negative.



(a)

$$V = \frac{kq}{r} = \frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(+4.0\times10^{-8}\ \mathrm{C}\right)}{1.2\ \mathrm{m}}$$

$$= +300\ \mathrm{V}$$

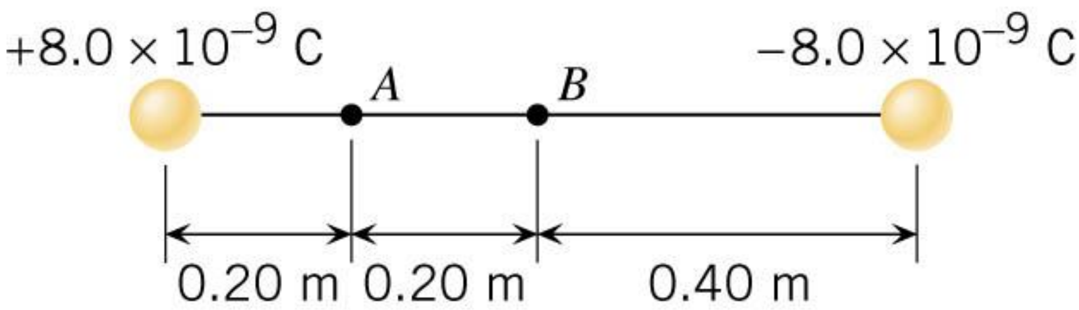


(b)

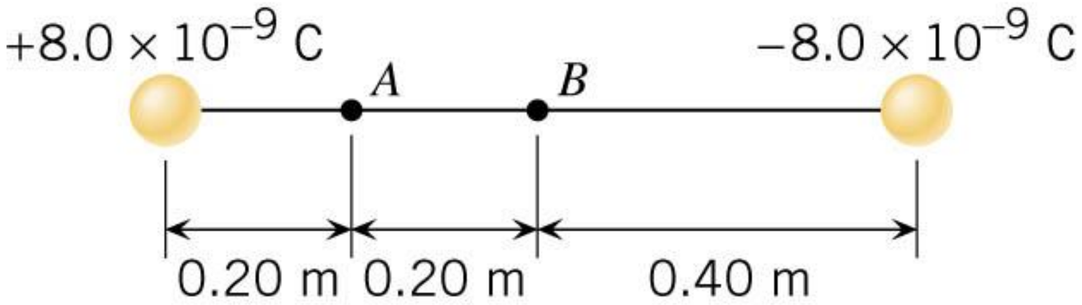
$$V = -300\ \mathrm{V}$$

Example 6 The Total Electric Potential

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

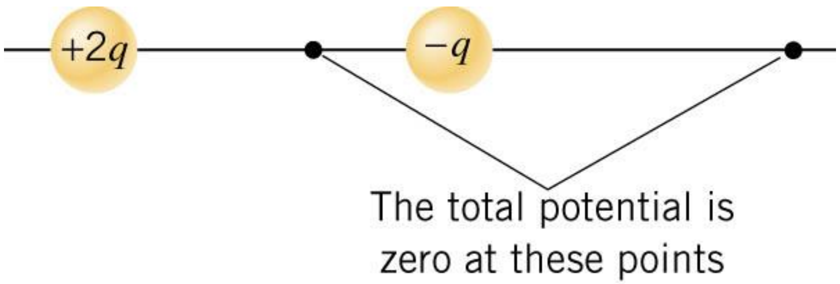


19.3 *The Electric Potential Difference Created by Point Charges*



$$V_A = \frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(+8.0\times10^{-9}\,\mathrm{C}\right)}{0.20\ \mathrm{m}} + \frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(-8.0\times10^{-9}\,\mathrm{C}\right)}{0.60\ \mathrm{m}} = +240\ \mathrm{V}$$

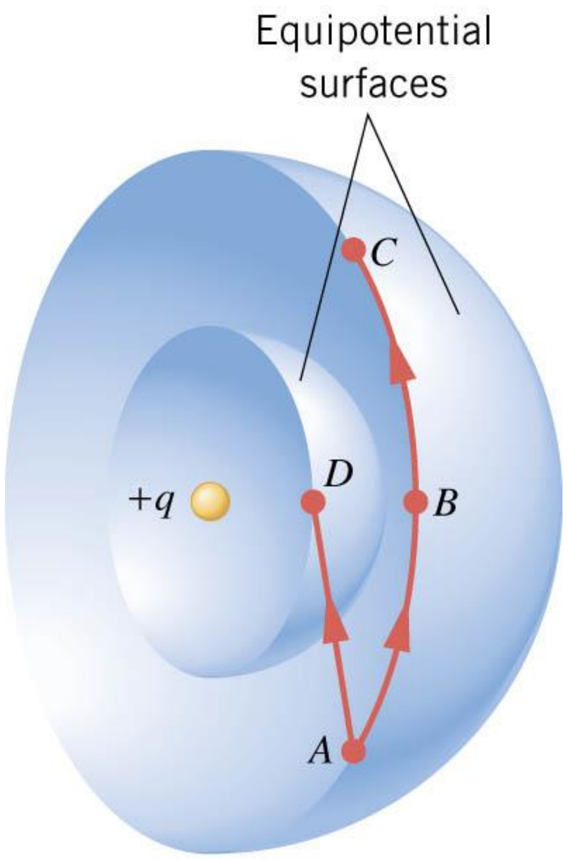
$$V_B = \frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(+8.0\times10^{-9}\,\mathrm{C}\right)}{0.40\ \mathrm{m}} + \frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(-8.0\times10^{-9}\,\mathrm{C}\right)}{0.40\ \mathrm{m}} = 0\ \mathrm{V}$$



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?

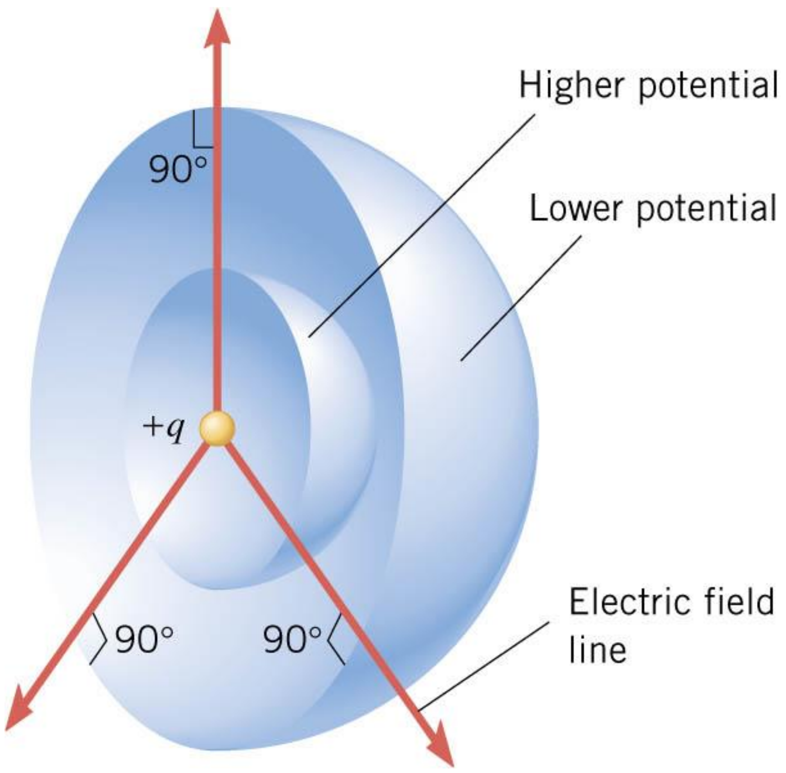
An ***equipotential surface*** is a surface on which the electric potential is the same everywhere.



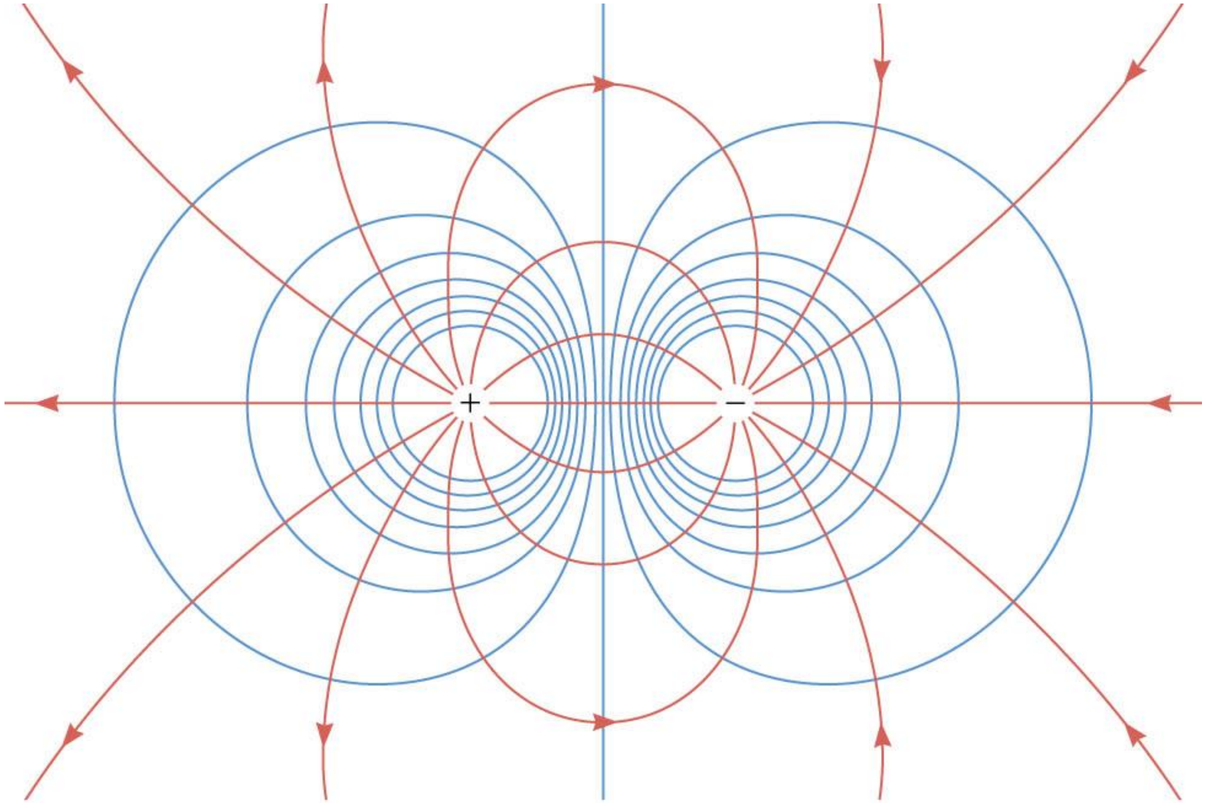
$$V = \frac{kq}{r}$$

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

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.

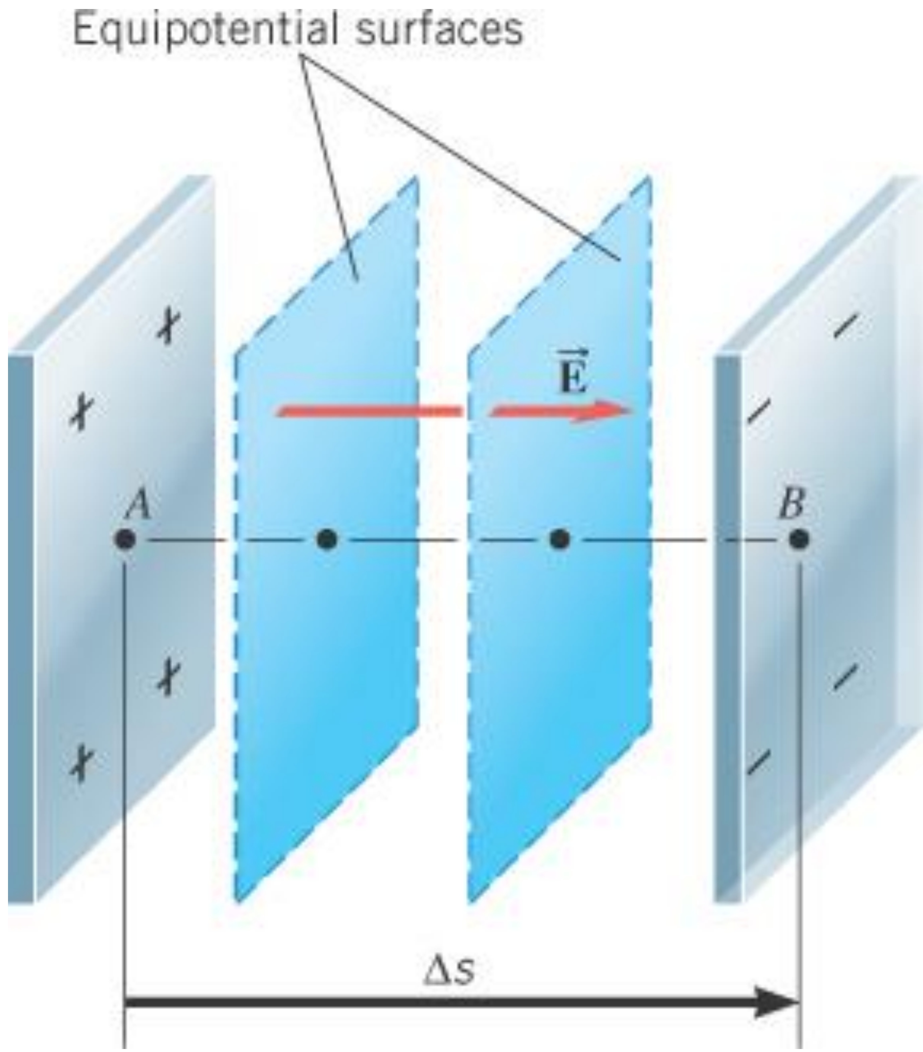


19.4 Equipotential Surfaces and Their Relation to the Electric Field



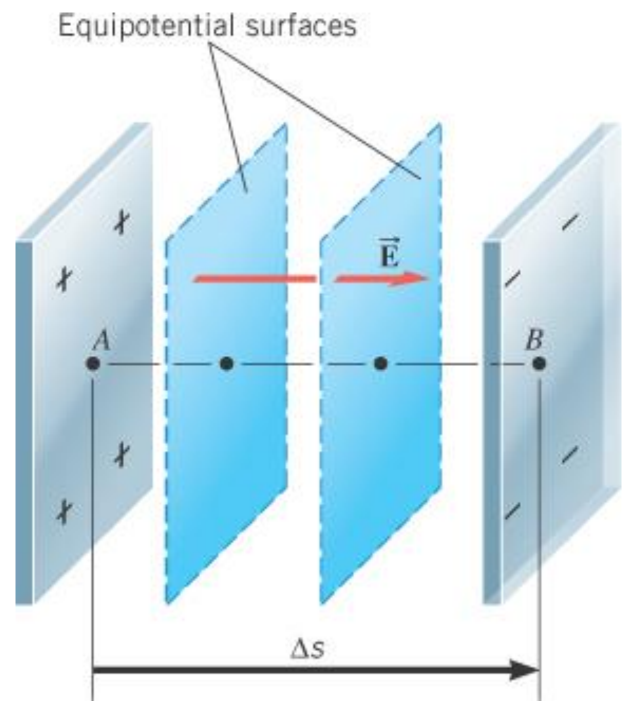
19.4 Equipotential Surfaces and Their Relation to the Electric Field

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

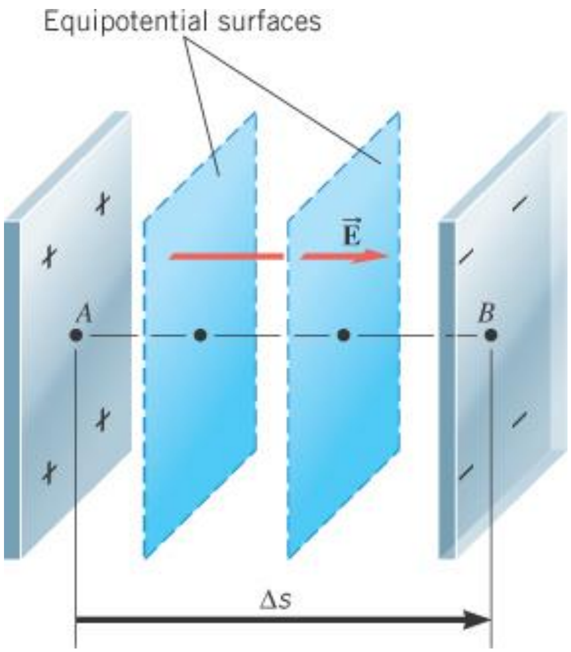


Example 9 The Electric Field and Potential Are Related

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



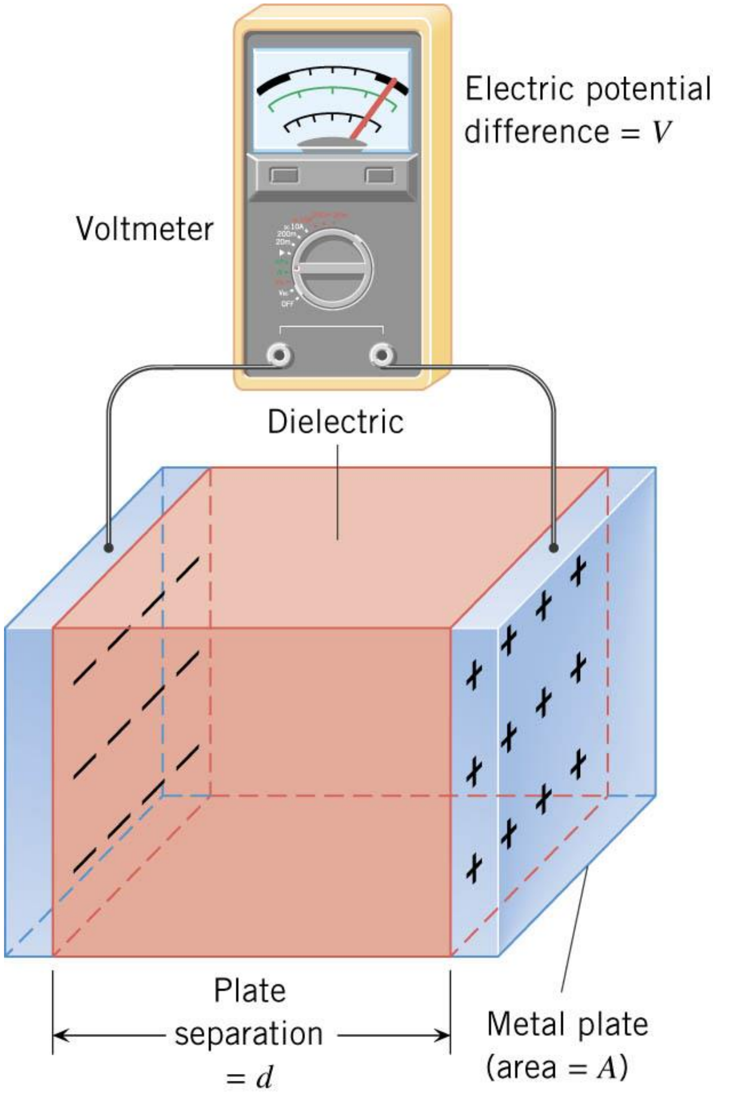
$$E = -\frac{\Delta V}{\Delta s} = \frac{-64\text{ V}}{0.032\text{ m}} = 2.0\times10^{3}\text{ V/m}$$



$$\Delta s = -\frac{\Delta V}{E} = -\frac{-3.0\text{ V}}{2.0\times10^{3}\text{ V/m}} = 1.5\times10^{-3}\text{ m}$$

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***.



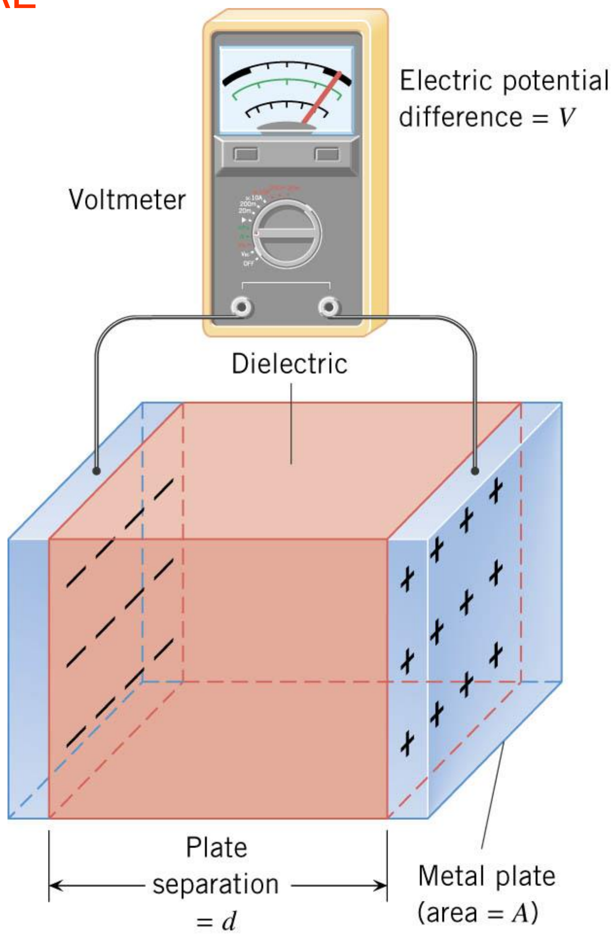
THE RELATION BETWEEN CHARGE AND POTENTIAL DIFFERENCE FOR A CAPACITOR

The magnitude of the charge on 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.

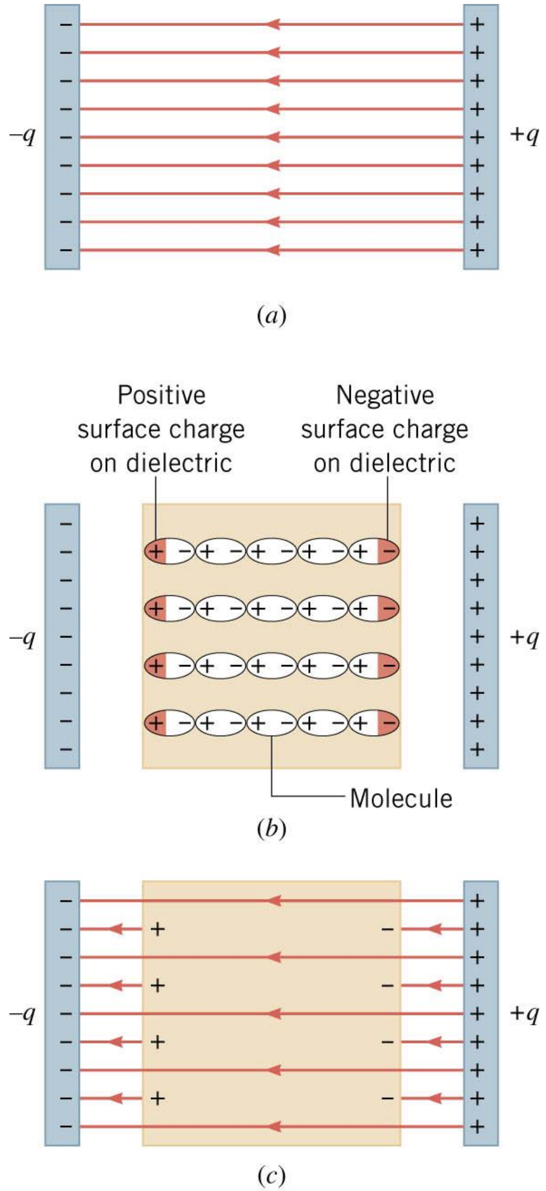
SI Unit of Capacitance: coulomb/volt = farad (F)



19.5 Capacitors and Dielectrics

THE DIELECTRIC CONSTANT

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



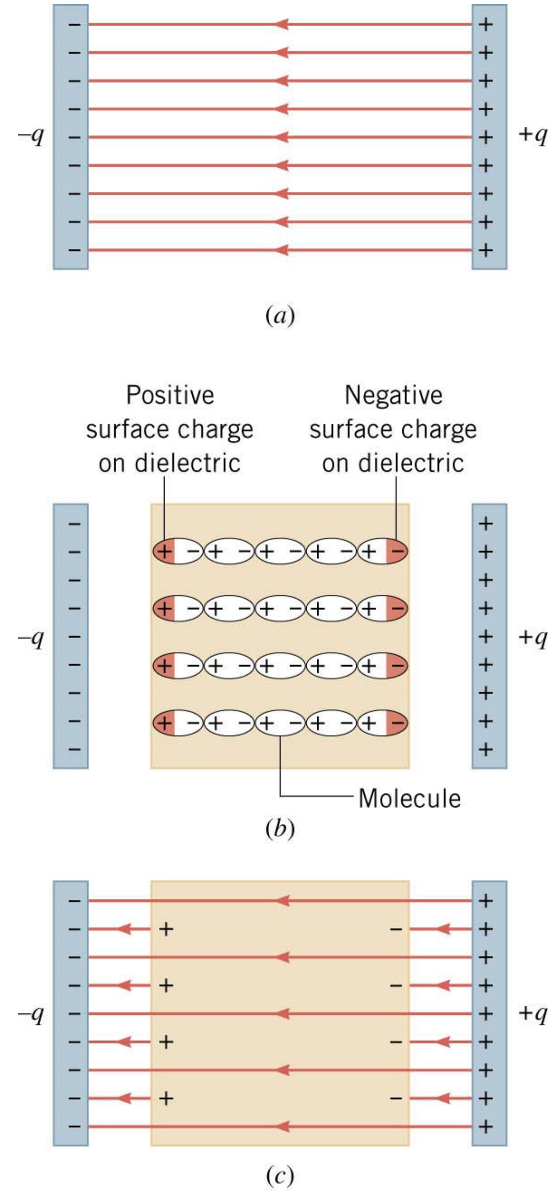
Dielectric constant

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

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

[a]Near room temperature.



19.5 Capacitors and Dielectrics

THE CAPACITANCE OF A PARALLEL PLATE CAPACITOR

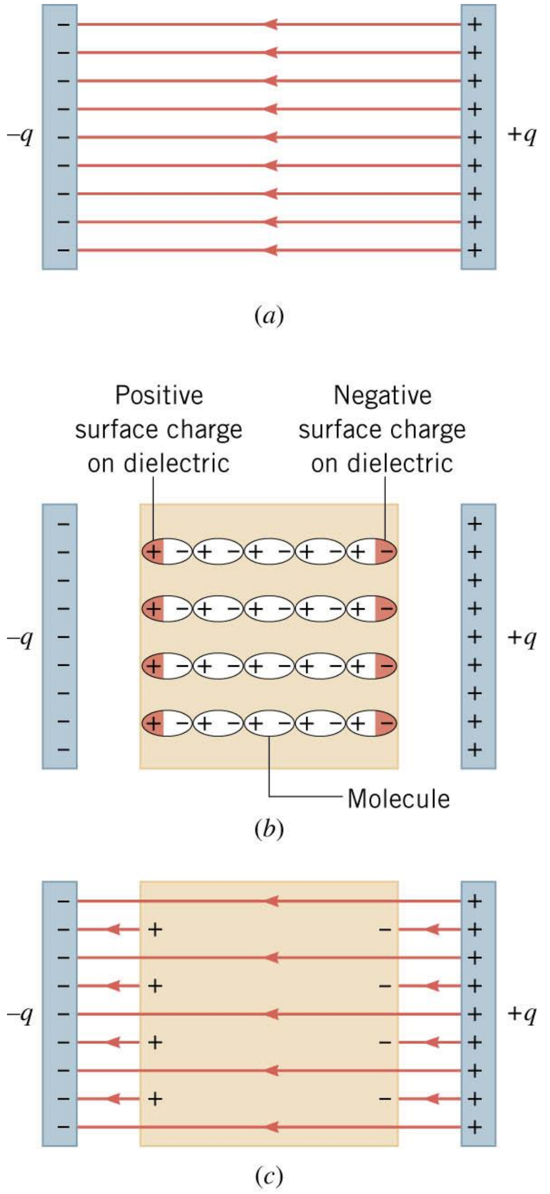
$$E_o = q/(\varepsilon_o A)$$

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

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

Parallel plate capacitor filled with a dielectric

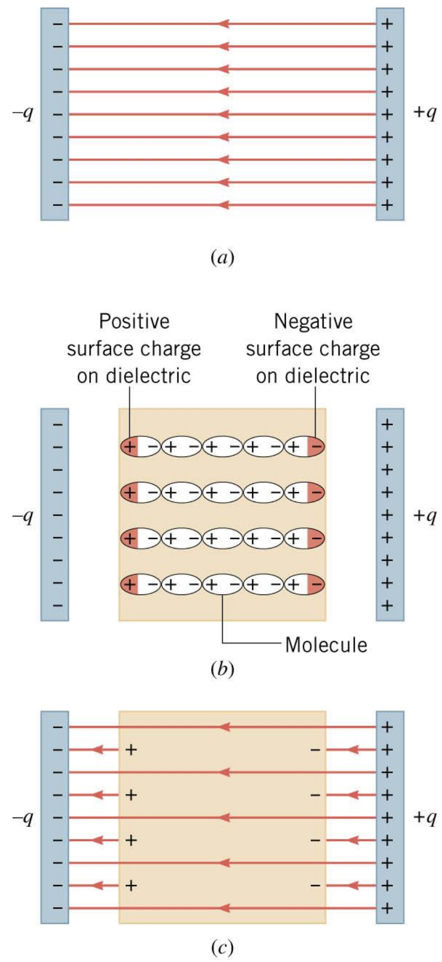
$$C = \frac{\kappa \varepsilon_o A}{d}$$



(a) (b) (c)

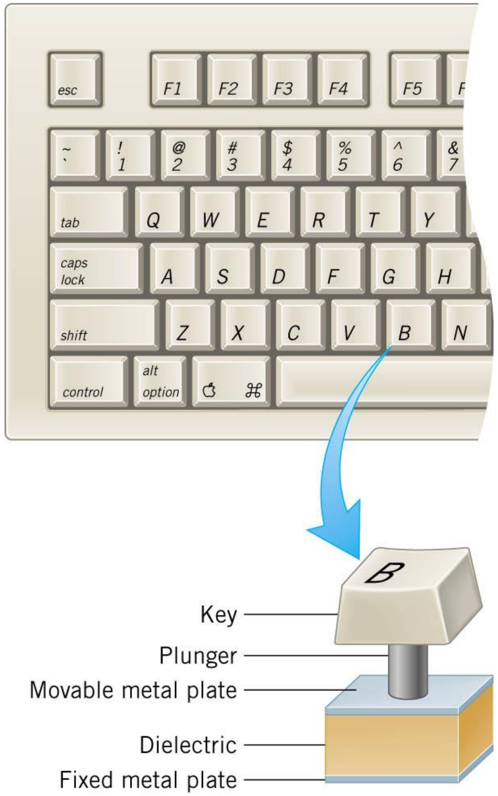
Conceptual Example 11 The Effect of a Dielectric When a Capacitor Has a Constant Charge

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?



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 $9.50\text{x}10^{-5}\text{m}^2$ and the capacitor is filled with a material whose dielectric constant is 3.50.

Determine the change in capacitance detected by the computer.

$$C = \frac{\kappa \varepsilon_o A}{d} = \frac{(3.50)\left(8.85\times10^{-12}\,\mathrm{C}^2/\left(\mathrm{N}\cdot\mathrm{m}^2\right)\right)\left(9.50\times10^{-5}\,\mathrm{m}^2\right)}{0.150\times10^{-3}\,\mathrm{m}} = 19.6\times10^{-12}\,\mathrm{F}$$

$$C = \frac{\kappa \varepsilon_o A}{d} = \frac{(3.50)\left(8.85\times10^{-12}\,\mathrm{C}^2/\left(\mathrm{N}\cdot\mathrm{m}^2\right)\right)\left(9.50\times10^{-5}\,\mathrm{m}^2\right)}{5.00\times10^{-3}\,\mathrm{m}} = 0.589\times10^{-12}\,\mathrm{F}$$

$$\Delta C = 19.0\times10^{-12}\,\mathrm{F}$$

ENERGY STORAGE IN A CAPACITOR

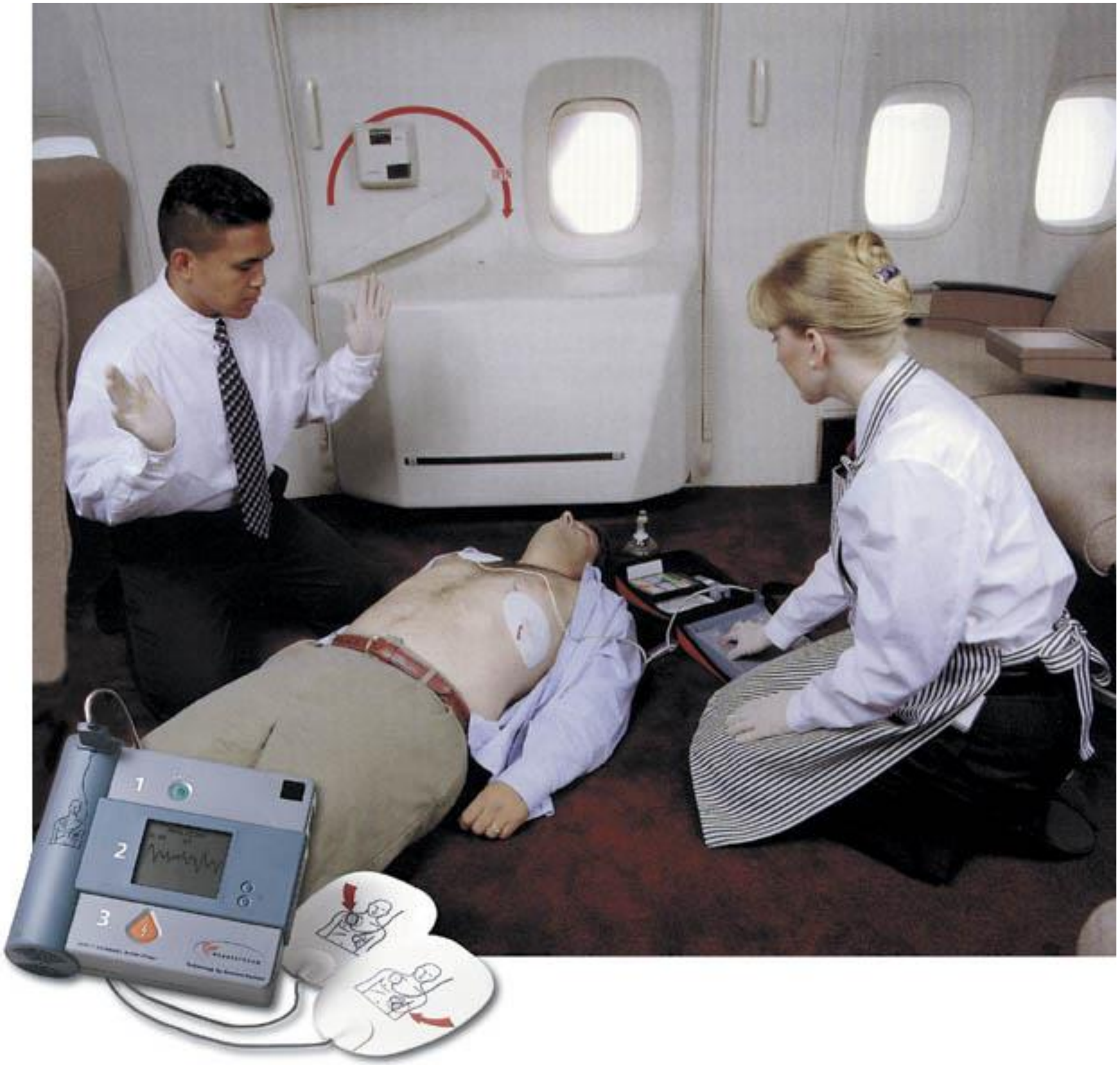
$$\text{Energy} = \tfrac{1}{2} C V^2$$

$$\text{Volume} = Ad$$

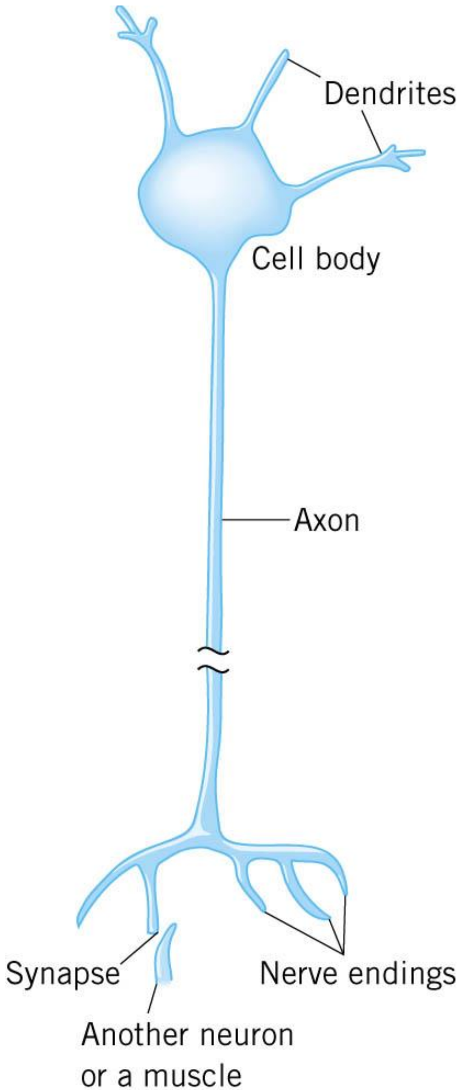
$$\text{Energy} = \tfrac{1}{2}\left(\frac{\kappa \varepsilon_o A}{d}\right)(Ed)^2$$

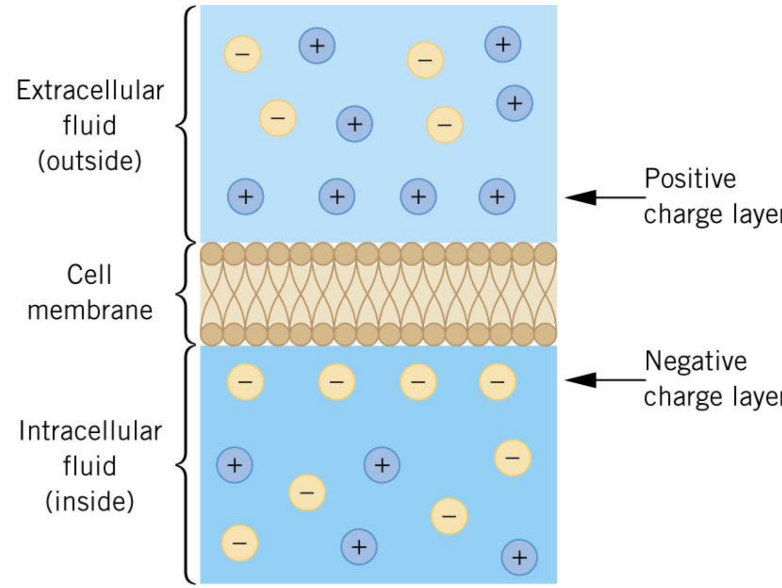
$$\text{Energy density} = \frac{\text{Energy}}{\text{Volume}} = \tfrac{1}{2}\kappa \varepsilon_o E^2$$

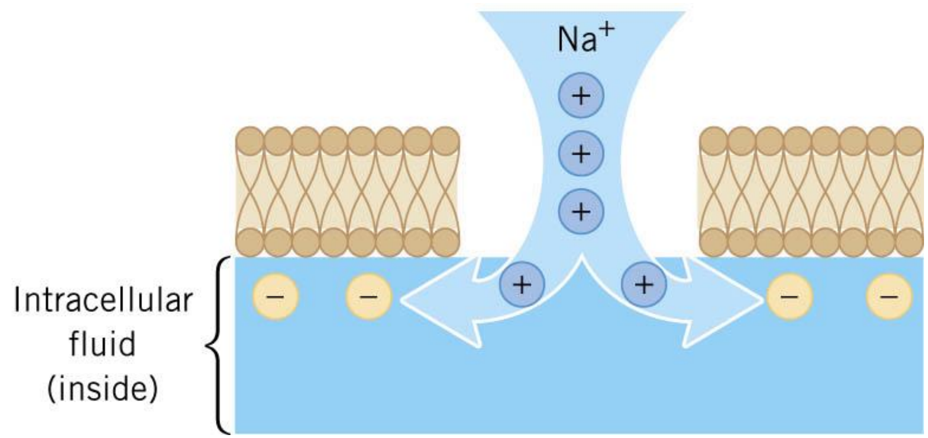
19.6 Biomedical Applications of Electrical Potential Differences

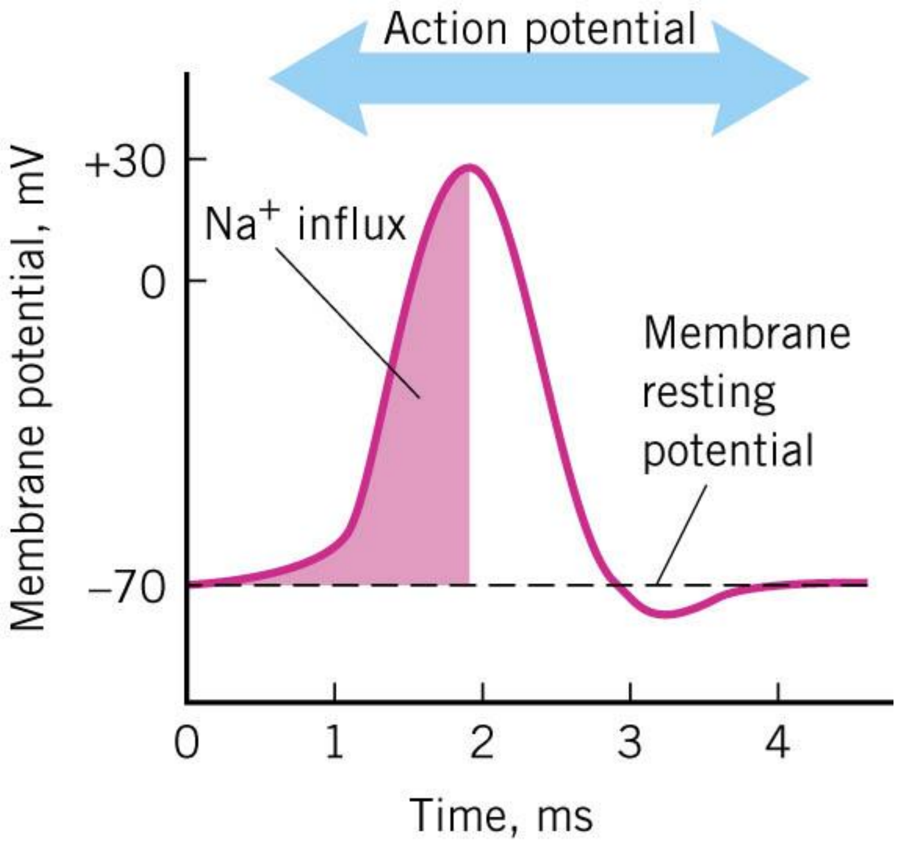


19.6 Biomedical Applications of Electrical Potential Differences

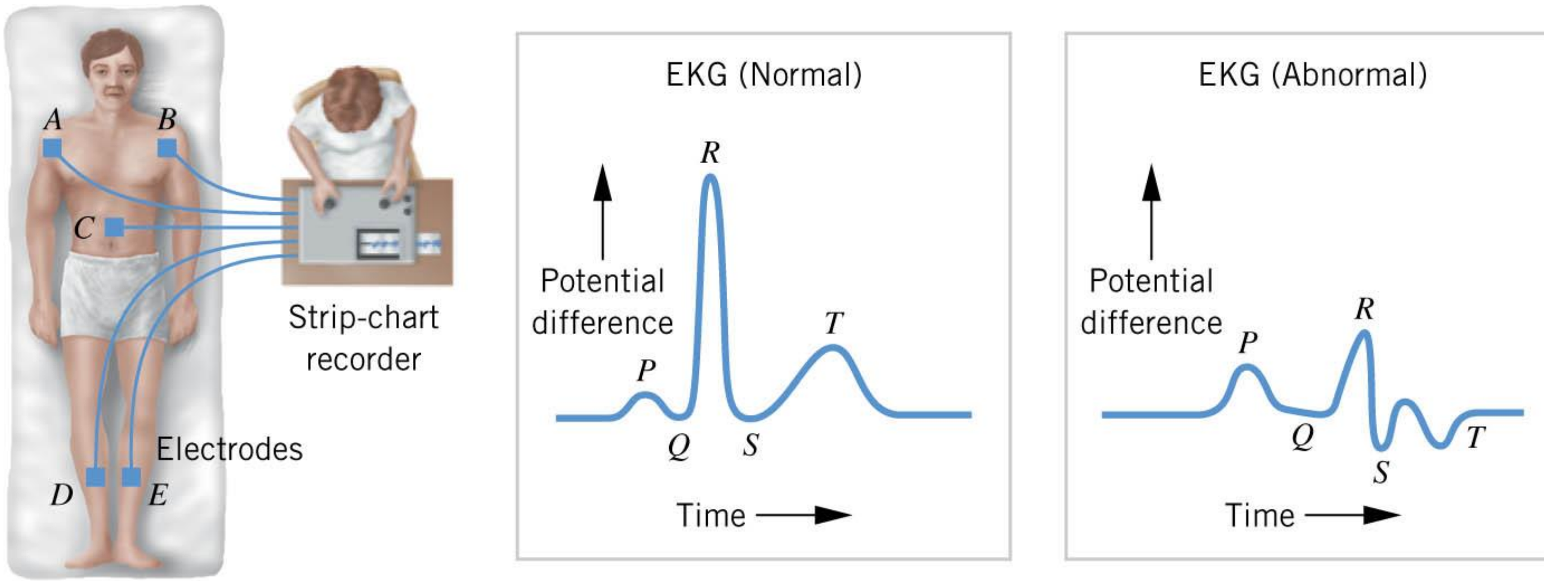




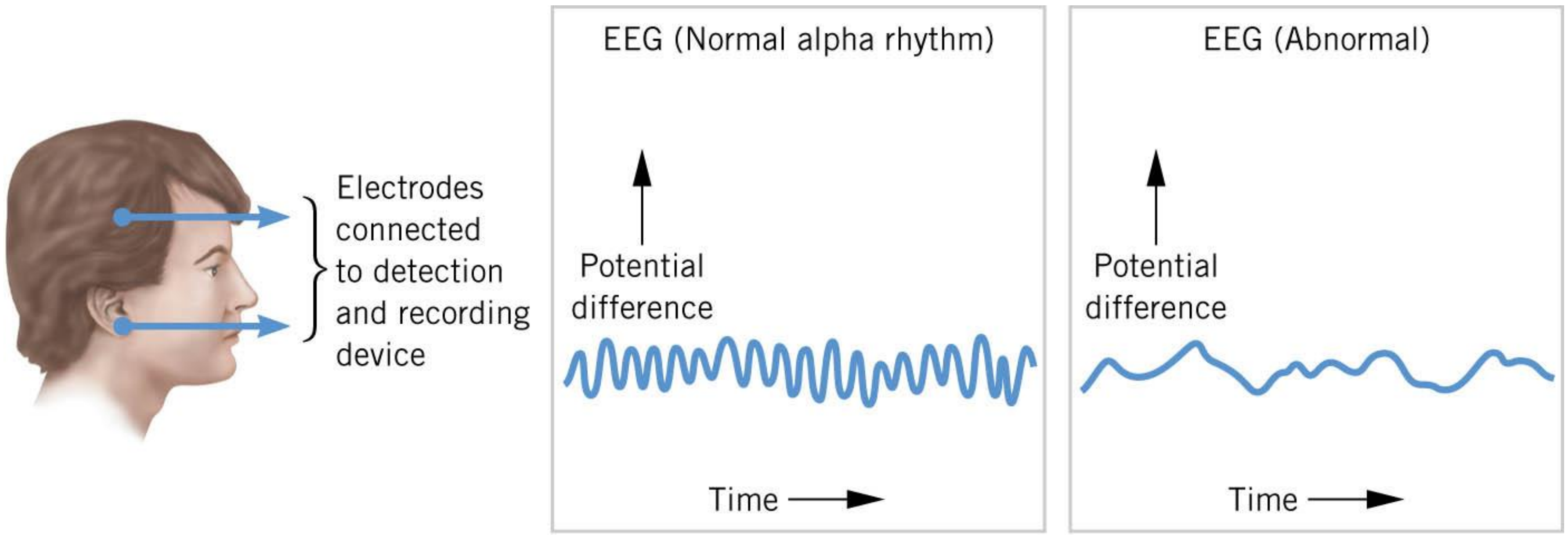



Action potential
+30
0
–70
Na+ influx
Membrane resting potential
Membrane potential, mV
0
1
2
3
4
Time, ms

19.6 Biomedical Applications of Electrical Potential Differences



19.6 Biomedical Applications of Electrical Potential Differences



19.6 Biomedical Applications of Electrical Potential Differences