At equilibrium under electrostatic conditions, any excess charge resides on the surface of a conductor.

At equilibrium under electrostatic conditions, the electric field is zero at any point within a conducting material.

The conductor shields any charge within it from electric fields created outside the conductor.
The electric field just outside the surface of a conductor is perpendicular to the surface at equilibrium under electrostatic conditions.
Chapter 17

Electric Potential
Potential Energy

The work done by the gravitational field on the ball in going from A to B equals the difference between the gravitational potential energy at A \((\text{GPE}_A)\) and the gravitational potential energy at B \((\text{GPE}_B)\)

\[
W_{BA} = mgh_A - mgh_B = \text{GPE}_A - \text{GPE}_B
\]
Potential Energy

Analogous situation between the work done by the gravitational field on the ball and the work done by the electric field on the charge.
**Potential Energy**

The work done by the electric field on the charge in going from A to B equals the difference between the electric potential energy at A ($E_{PE_A}$) and the electric potential energy at B ($E_{PE_B}$)

\[ W_{BA} = E_{PE_A} - E_{PE_B} \]

Note that the electric force is a conservative force just like the gravitational force so the work done by it is independent of the path taken between A and B.
**The Electric Potential Difference**

\[
\frac{W_{BA}}{q_o} = \frac{\text{EPE}_A}{q_o} - \frac{\text{EPE}_B}{q_o}
\]

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

\[ V = \frac{\text{EPE}}{q_o} \]

( note analogy with definition of electric field, \( E = \frac{F}{q_o} \) )

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

\[ V_B - V_A = \frac{\text{EPE}_B}{q_o} - \frac{\text{EPE}_A}{q_o} = \frac{-W_{BA}}{q_o} \]

**Potential difference:**
as with potential energy, only differences in \( V \) matter physically

\[ V_{BA} = \Delta V = \frac{\Delta(\text{EPE})}{q_o} = \frac{-W_{BA}}{q_o} \]
Common usages of electric potential

- flashlight battery: 1.5 V
- car battery: 12 V
- electrical outlet (US): 120 V
- electrical outlet (Europe): 220 V
- small Van de Graaff generator: 100,000 V
- large Van de Graaff generator: 5,000,000 V
- medium lightning bolt: 35,000,000 V
Schematic view of a Van De Graaff generator.

1. hollow metallic sphere
2. electrode connected to the sphere
3. upper roller
4. side of the belt with positive charges (going up)
5. opposite side of the belt with negative charges (going down)
6. lower roller (metal) turned by motor
7. lower electrode (ground)
8. spherical device with negative charges
9. spark produced by the difference of potentials
**Example: Work, Potential Energy, and Electric Potential**

The work done by the electric force as the test charge (+2.0x10^{-6}C) moves from A to B is +5.0x10^{-5}J.

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

(b) Determine the potential difference between these points.

\[ W_{BA} = EPE_A - EPE_B \]

\[ V_B - V_A = \frac{EPE_B}{q_0} - \frac{EPE_A}{q_0} = -\frac{W_{BA}}{q_0} \]
The Electric Potential Difference

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

\[ \text{EPE}_B - \text{EPE}_A = -W_{BA} = -5.0 \times 10^{-5} \text{ J} \]

(b)

\[ V_B - V_A = \frac{-W_{BA}}{q_o} = \frac{-5.0 \times 10^{-5} \text{ J}}{2.0 \times 10^{-6} \text{ C}} = -25 \text{ V} \]
Conceptual Example: 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.
We now include electric potential energy $E_{PE}$ as part of the total energy that an object can have:

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

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.

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

The eV is a unit of energy, but not an SI unit
-- useful in describing the energies of subatomic particles, e.g. KeV -- thousand eV, MeV -- million eV, GeV -- billion eV
Van de Graaff generator used as a particle accelerator. An electron is accelerated vertically starting from rest across a +100,000 V potential difference produced by a Van de Graaff. Find a) the change in electric potential energy of the electron, b) the kinetic energy gained by the electron (neglecting gravity) and c) the final speed of the electron. For fun, compare the result in a) with the change in the gravitational potential energy of the electron assuming the Van de Graaff is 1 m tall.

\[ V_B = +10^5 \text{ V} \]

\[ V_A = 0 \text{ V} \]

\[ q = -1.6 \times 10^{-19} \text{ C} \]

\[ m_e = 9.11 \times 10^{-31} \text{ kg} \]

\[ v_A = 0 \text{ m/s} \]

\[ V \]

a) \[ \text{EPE}_B - \text{EPE}_A = qV_B - qV_A = q(V_B - V_A) \]

\[ = (-1.6 \times 10^{-19})(10^5 - 0) = -1.6 \times 10^{-14} \text{ J} \]

EPE decreases

b) Conservation of energy: \[ KE_B + \text{EPE}_B = KE_A + \text{EPE}_A \]

\[ KE_B = KE_A - (\text{EPE}_B - \text{EPE}_A) = 0 - (-1.6 \times 10^{-14}) \]

\[ = 1.6 \times 10^{-14} \text{ J} = 10^5 \text{ eV} = 100 \text{ KeV} \]

q = -1.6 \times 10^{-19} \text{ C}, m_e = 9.11 \times 10^{-31} \text{ kg}
Van de Graaff example -- continued

c) \(K E_B = \frac{1}{2} m_e v_B^2\)

\[
v_B = \left[\frac{2K E_B}{m_e}\right]^{1/2} = \left[\frac{2(1.6 \times 10^{-14})}{(9.11 \times 10^{-31})}\right]^{1/2}
\]

\[= 1.87 \times 10^8 \text{ m/s}\]

The speed of light is \(3.0 \times 10^8 \text{ m/s}\), so this calculation would tell us that the electron is traveling at \(~ 2/3\) of the speed of light! To do part c) correctly, we really should use Einstein’s Theory of Special Relativity (gives \(1.64 \times 10^8 \text{ m/s}\))

Fun calculation: compare \(E P E_B - E P E_A\) from a) with \(G P E_B - G P E_A\) for electron.

\(G P E_B - G P E_A = m_e g h_B - m_e g h_A = m_e g (h_B - h_A)\)

\[= (9.11 \times 10^{-31})(9.8)(1 - 0)\]

\[= 8.93 \times 10^{-30} \text{ J}\]

From a), \(E P E_B - E P E_A = -1.6 \times 10^{-14} \text{ J}\)

\((1.6 \times 10^{-14})/(8.93 \times 10^{-30}) = 1.79 \times 10^{15}\), GPE can be neglected for an electron!!
The Electric Potential Difference Created by Point Charges

A positive test charge $q_0$ is being repelled by another positive point charge $q$. Since the force on $q_0$ is not constant between A and B, integral calculus must be used to find the work done by the force acting from A to B,

$$W_{BA} = \frac{kqq_0}{r_A} - \frac{kqq_0}{r_B}$$

The potential difference between A and B is,

$$V_B - V_A = \frac{-W_{BA}}{q_0} = \frac{kq}{r_B} - \frac{kq}{r_A}$$

If $r_B$ goes to infinity, and defining $V_B = 0$ at infinity, and letting $r_A \to r$ and $V_A \to V$,

**Potential of a point charge** 

$$V = \frac{kq}{r}$$
The Electric Potential Difference Created by Point Charges

Example: The Potential of a Point Charge

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

(a) 

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

A positive point charge raises the potential.

(b) 

\[ V = -300 \text{ V} \]

A negative point charge lowers the potential.
The Electric Potential Difference Created by Point Charges

When two or more charges are present, the potential due to all of the charges is obtained by adding together the individual potentials.

Example: The Total Electric Potential

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

\[ +8.0 \times 10^{-9} \text{ C} \quad A \quad B \quad -8.0 \times 10^{-9} \text{ C} \]

0.20 m 0.20 m 0.40 m
The Electric Potential Difference Created by Point Charges

\[ V_A = \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}{0.20 \text{ m}} \frac{+8.0 \times 10^{-9} \text{ C}}{0.20 \text{ m}} + \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}{0.40 \text{ m}} \frac{-8.0 \times 10^{-9} \text{ C}}{0.40 \text{ m}} = +240 \text{ V} \]

\[ V_B = \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}{0.40 \text{ m}} \frac{+8.0 \times 10^{-9} \text{ C}}{0.40 \text{ m}} + \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}{0.40 \text{ m}} \frac{-8.0 \times 10^{-9} \text{ C}}{0.40 \text{ m}} = 0 \text{ V} \]
**Conceptual Example: 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?