Today: Ch 19 2nd 1/3rd Electric Potential
Wednesday: Ch 19 3rd 1/3rd Electric Potential
Lab:        4, DC Electronics

Redo8; HW10: Ch 19: Pr 2,4
Redo9; HW11: Ch 19: Pr 6, 12, 14,16

Equipment:
  Faraday’s Ice bucket
  Electrometer
  Rabbit fur and rod
  Capacitor plates (and insulator)

Administrative:

Last Time
18.1 The Electric Field Inside a Conductor: Shielding
  • What electric field does this distribution of charge produce?
  • Moral: The electric field at the surface of a conductor is perpendicular to the surface.
  • What about inside the conductor?
  • What about outside the conductor?

18.2 Gauss’ Law

Chapter 19 Electric Potential Energy and the Electric Potential (Voltage)
19.1 Potential Energy
  • Work – Energy Relation
    o Work
    o Kinetic Energy
  • Conservative Force
  • Potential Energy
  • Gravitational Potential Energy
  • Electrical Potential Energy
    o \( W_{p\rightarrow q} = -qE\Delta h = -\Delta P.E. \)

19.2 The Electric Potential Difference
  • Definition: \( \Delta V = \frac{\Delta P.E.}{q_1} \) Units: J/c = Volt (V).
  • Lab tie-in

This Time
19.2.1 Simple Applications

- **Example 1: Parallel Plate Capacitor Revisited:** The two charged plates we considered before are held at a potential difference of 10 kV, say the – plate at –5kV and the + plate at + 5kV. The electron is injected through the hole in the – plate and is accelerated by the electric field as it flies toward the hole in the + plate. How fast is it going when it reaches the + plate?
  
  - **Quantities**
    - $\Delta V = 10 \text{kV}$
    - $q_e = -e = 1.6 \times 10^{-19} \text{C}$
    - $m = 9.11 \times 10^{-31} \text{kg}$
    - $v_i = 0$
    - $v_f = ?$
  
  - **Relations**
    - $\Delta V = \frac{\Delta P E_1}{q_1} \Rightarrow \Delta P E_c = q_e \Delta V = -e \Delta V$
    - $\Delta K.E. = -\Delta P E_c$
    - $\Delta K.E. = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2 \Rightarrow v_f = \sqrt{\frac{2 \Delta K.E.}{m}}$
  
  - **Algebra / Numbers**
    - $v_f = \sqrt{\frac{2 \Delta K.E.}{m}}$
    - $\Delta K.E. = -\Delta P E_c$
      - $\Delta P E_c = -e \Delta V$
    - $\Delta K.E. = -e \Delta V = e \Delta V$
    - $v_f = \sqrt{\frac{2e\Delta V}{m}}$
    - $v_f = \sqrt{\frac{2 \cdot 1.6 \times 10^{-19} \text{C} \cdot 10,000 \text{V}}{9.11 \times 10^{-31} \text{kg}}} = 5.9 \times 10^7 \text{ m/s}$

- **Example:**
  
  - **Set-up:** In Scanning Tunneling Microscopy, a sharp metal tip is held just above a conducting surface, the two are held at different voltages, $V_t$ and $V_s$. When the tip is close enough to the surface, some electrons jump the gap between them. If the surface is coated with some material, say atomic hydrogen, then when the electrons hit the surface with kinetic energy equaling the energy difference between the atom’s bonding and anti-bonding states, the beam of electrons can desorb the atoms.
Show Image of surface on which we did this

Example 2: If this condition is met when the electrons hit the surface at about 9.4\times10^5 \text{ m/s}, (a) How much work is done in accelerating the electron from rest? (b) what is the potential difference, \( V_s - V_t \) ?

- **Quantities**
  - \( v_f = 9.4\times10^5 \text{ m/s} \)
  - \( v_i = 0 \)
  - \( q_e = -e = 1.6\times10^{-19} \text{ C} \)
  - \( m = 9.11\times10^{-31} \text{ kg} \)
  - \( W = ? \)
  - \( \Delta V = V_s - V_t = ? \)

- **Relations**
  \[
  W = \Delta K.E. = -\Delta P.E. \\
  \Delta P.E. = q\Delta V = -e\Delta V \\
  \Delta K.E. = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = \frac{1}{2}mv_f^2
  \]

  a) **Algebra / Numbers**
  
  \[
  W = \Delta K.E. \\
  \frac{\Delta K.E.}{\frac{1}{2}mv_f^2} = 4.0\times10^{-19} \text{ J}
  \]

  b) **Algebra / Numbers**
  
  \[
  \Delta V = \Delta P.E. \\
  e \\
  W = -\Delta P.E. \\
  \frac{\Delta V}{W} = \frac{-W}{e} = \frac{4.0\times10^{-19} \text{ J}}{1.6\times10^{-19} \text{ C}} = 2.5 \text{ Volts}
  \]

Which piece has the more + voltage? \( \Delta V = V_s - V_t = 2.5 \text{ Volts} \); the surface, that pulls the electrons to it.

19.3 The Electric Potential Difference due to Point Charges

**Point Charges: Force, Field, Potential Energy, and Potential**

- Coulomb’s **Electric Force** law says For two charged particles interacting:
  
  \[
  \vec{F}_{q \rightarrow q} = k \frac{qQ}{r^2} \vec{r} \quad \text{Where the r vector gives the location of q relative to Q.}
  \]

- Then with **Electric Field**, we said, regardless of whether or not there is a particle of charge q out there, the particle of charge Q is still responsible for an Electric Field of
  
  \[
  \vec{E}(\vec{r}) = \frac{\vec{F}_{Q \rightarrow q}}{q} = k \frac{Q}{r^2} \vec{r}
  \]

- The **Work** done by the electric force in, say, brining charge q in from an initial to a final position is
  
  \[
  W_{Q \rightarrow q} = \int_i^f \vec{F}_{Q \rightarrow q} \cdot d\vec{r} = \int_i^f k \frac{qQ}{r^2} \vec{r} \cdot d\vec{r} = kqQ \int_i^f \frac{dr}{r^2} = kqQ \left( \frac{-1}{r_f} - \frac{-1}{r_i} \right) = k \frac{qQ}{r_i} - k \frac{qQ}{r_f}
  \]
Physics 221                                      Lecture 12                           February 10th, 2003

- The **change in Electric Potential Energy** of two point charges interacting is
  \[ \Delta P.E. = -W_{q\rightarrow q} = k \frac{qQ}{r_f} - k \frac{qQ}{r_i} \]

- **Class Work: Potential Energy**: What is the change in potential energy of an electron and a proton if they are brought in from infinity to their Hydrogen ground state separation of 5.29×10^{-11} m?
  - \( q = -e \)
  - \( Q = e \)
  - \( r_f = r_{\text{Bohr}} = 5.29 \times 10^{-11} \text{ m} \)
  - \( r_i = \text{ infinity} \)

  \[ \Delta P.E. = k \frac{qQ}{r_f} - k \frac{qQ}{r_i} = k \frac{-e}{r_{\text{Bohr}}} - k \frac{-e}{\infty} = -k \frac{e^2}{r_{\text{Bohr}}} \]

  \[ \Delta P.E. = -8.99 \times 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2} \left( \frac{1.60 \times 10^{-19} \text{ C}}{5.29 \times 10^{-11} \text{ m}} \right)^2 = -4.35 \times 10^{-18} \text{ J} \]

- **Ionization**: This is very close to the energy required to ionize a H atom. For that we’d also need to take into consideration the change in kinetic energy, from orbiting the proton to just hanging out at some distant point. Later in the semester, that consideration will tell us we need ½ this energy.

- **Electric Potential**: Independent of whether or not there is a charge \( q \), there is a Potential difference between these two points in space of
  \[ \Delta V = \frac{\Delta P.E.}{q} = k \frac{Q}{r_f} - k \frac{Q}{r_i} \]

  - **Reference point**: As with potential energy, electric potential is physically meaningful only in the context of a *difference*: the difference in electric potential at one location vs. that at another. However, there is often a natural reference location, which is only implicitly considered. In the case of point charges, such as electrons and ions, the implicit location is infinity.

  \[ V(r) = k \frac{Q}{r} \] (implicitly comparing the voltage at point \( r \) to that at infinity).

- **Example 3: Potential**: What is the change in electric potential of an electron and a proton if they are brought in from infinity to their Hydrogen ground state separation of \( r_{\text{Bohr}} = 5.29 \times 10^{-11} \text{ m} \)?

  \[ \Delta V = \frac{\Delta P.E.}{q} = k \frac{Q}{r_f} - k \frac{Q}{r_i} = k \frac{e}{r_{\text{Bohr}}} - k \frac{e}{\infty} = k \frac{e}{r_{\text{Bohr}}} \]

  \[ \Delta V = 8.99 \times 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2} \left( \frac{1.60 \times 10^{-19} \text{ C}}{5.29 \times 10^{-11} \text{ m}} \right) = 27.2 \text{ Volts} \]

  - Or going back from here to write the change in electric potential:
    \[ \Delta P.E. = q\Delta V = -e\Delta V = -27.2 \cdot e \cdot \text{Volts} = -4.35 \times 10^{-18} \text{ J} \]
Pause: Summing up the electric interaction equations encountered thus far:

- **Electric Force:** \( \vec{F}_{q\rightarrow q} = k \frac{qQ}{r^2} \hat{r} \)

- **Electric Field:** \( \vec{E}(\vec{r}) = \frac{\vec{F}_{q\rightarrow q}}{q} = k \frac{Q}{r^2} \hat{r} \)

- **Work:** \( W_{q\rightarrow q} = k \frac{qO}{r_i} - k \frac{qO}{r_f} \)

- **Electric Potential Energy:** \( \Delta P.E. = -W_{q\rightarrow q} = k \frac{qO}{r_f} - k \frac{qO}{r_i} \)

- **Electric Potential:** \( V(r) = k \frac{Q}{r} \)

- **eV** which is the *other* acceptable unit of energy.
  - Since the underlying glue that binds your molecules together is electric, and the players are a hand full of protons and electrons – with charge e or –e, if you worked out the energy of any process of interest: ionization, excitation, bonding, breaking... you’d always end-up with a factor of e in your final expression. So we get lazy about substituting \( e = 1.60 \times 10^{-19} \text{C} \). we leave the e in there.

- Ex: In the above example, we’d simply write \( \Delta P.E. = q\Delta V = -e\Delta V = -27.2 \cdot e \cdot \text{Volts} = -27.2 eV \). The “electron Volt, eV” is a measure of energy, specifically, how much an electron’s or proton’s energy would change if moved through a potential difference of 1 Volt.

- **eV, U-V, and Life as we know it**
  - This turns out being a very good scale of energy. All chemical processes take, ‘about an eV’ of energy. Now, light is an oscillation in electric and magnetic fields. As you might imagine, charged particles in the presence of an oscillating electric field get shaken around. Unfortunately for life as we know it, UV light can deliver ‘about an eV’ of energy – UV light can knock apart chemical bonds – reduce us all to atoms again.
2 Charge Example 4: Note: Electric Potential is a scalar. This gets rid of all that direction bother we had in Pr. 28 of last chapter. What is the electric potential at \( x_0 \) and \( x_3 \) (relative to infinity)?

- **Quantities**
  - \( Q_1 = 8.00 \mu C \)
  - \( Q_2 = -21.00 \mu C \)
  - \( |r_{1-0}| = 0.03m \)
  - \( |r_{2-0}| = 0.06m \)
  - \( |r_{1-3}| = 0.03m \)
  - \( |r_{2-3}| = 0.09m \)

- **Relations / Algebra**
  - \( \Delta V_{\text{total}}(0) = \Delta V_1(0) + \Delta V_2(0) \)
    - \( \Delta V_1(0) = k \frac{Q_1}{r_{1-0}} - k \frac{Q}{r_{1-\infty}} = k \frac{Q_1}{r_{1-0}} \)
    - \( \Delta V_2(0) = k \frac{-Q_2}{r_{2-0}} \)
  - \( \Delta V_{\text{total}}(0) = \Delta V_1(0) + \Delta V_2(0) \)
  - \( \Delta V_{\text{total}}(0) = k \frac{Q_1}{r_{1-0}} + k \frac{-Q_2}{r_{2-0}} \)

\[ \Delta V_{\text{total}}(0) = 8.99 \times 10^9 \text{ Nm}^2/\text{C}^2 \left( \frac{8.00 \times 10^{-6} \text{ C}}{0.03m} - \frac{21.00 \times 10^{-6} \text{ C}}{0.09m} \right) \]

\[ \Delta V_{\text{total}}(0) = 3.00 \times 10^3 \text{ Volts} \]

- What would be the potential energy of an electron there (in eV’s)?
  - \( \Delta P.E. (0) = q\Delta V_{\text{total}}(0) = -3.00 \times 10^7 \text{ eV} \)
Example 1: Parallel Plate Capacitor Revisited:
The two charged plates we considered before are held at a potential difference of 10 kV, say the – plate at –5kV and the + plate at +5kV. The electron is injected through the hole in the – plate and is accelerated by the electric field as it flies toward the hole in the + plate. How fast is it going when it reaches the + plate?

Example 2: If this condition (enough energy to break H-Si bonds) is met when the electrons hit the surface at about $9.4 \times 10^5$ m/s, (a) How much work is done in accelerating the electron from rest? (b) what is the potential difference, $V_s - V_t$?
Class Work: Potential Energy: What is the change in potential energy of an electron and a proton if they are brought in from infinity to their Hydrogen ground state separation of $5.29 \times 10^{-11} \text{m}$?

Example 3: Potential: What is the change in electric potential of an electron and a proton if they are brought in from infinity to their Hydrogen ground state separation of $r_{\text{Bohr}} = 5.29 \times 10^{-11} \text{m}$?

2 Charge Example 4: Note: Electric Potential is a scalar. This gets rid of all that direction bother we had in Pr. 28 of last chapter. What is the electric potential at $x_0$ and $x_3$ (relative to infinity)?