PHYS 1444 – Section 501 Lecture #11

Wednesday, Mar. 1, 2006
Dr. Jaehoon Yu

- Microscopic View of Electric Current
- Ohm's Law in Microscopic View
- Superconductivity
- EMF and Terminal Voltage
- Resistors in Series and Parallel
- Energy losses in Resistors
- Kirchhoff's Rules

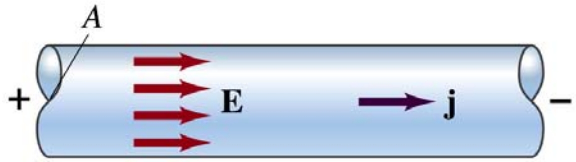
Today's homework is #6, due 7pm, Thursday, Mar. 8!!

Announcements

- Exam results
  - Class average: 53.3
  - Top score: 93
  - Will choose 2 best out of the three
  - Each of the two represents 22.5% of the grade
    - Remember what the homework proportion is?
      - 25%.
  - This is not the end of the world
- Cloud Chamber run
  - CPB opening ceremony is Friday (for big shots) and Saturday (public)
  - To prepare for this, we will have a test run of our prototype chamber from 3:30pm – 5:00pm tomorrow, Thursday, in CPB 115.
    - Ask the students there to let you see.

Microscopic View of Electric Current

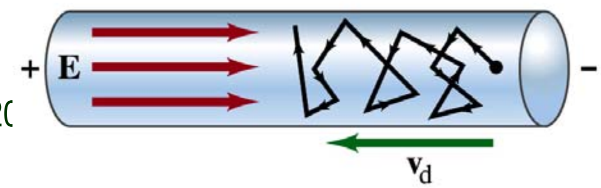
- When a potential difference is applied to the two ends of a wire w/ uniform cross-section, the direction of electric field is parallel to the walls of the wire, this is possible since the charges are moving, electrodynamics
- Let's define a microscopic vector quantity, the current density, **j**, the electric current per unit cross-sectional area
  - j=I/A or I = jA if the current density is uniform
  - If not uniform $I = \int \vec{j} \cdot d\vec{A}$
  - The direction of **j** is the direction the positive charge would move when placed at that position, generally the same as E



- The current density exists on any point in space while the current I refers to a conductor as a whole so a macroscopic

Microscopic View of Electric Current

- The direction of j is the direction of a positive charge. So in a conductor, since negatively charged electrons move, the direction is –**j**.
- Let's think about the current in a microscopic view again:
  - When voltage is applied to the end of a wire
  - Electric field is generated by the potential difference
  - Electrons feel force and get accelerated
  - Electrons soon reach to a steady average speed due to collisions with atoms in the wire, called drift velocity, v_d
  - The drift velocity is normally much smaller than electrons' average random speed.



Microscopic View of Electric Current

- How do we relate v_d with the macroscopic current I?
  - In time interval Δt, the electrons travel $l = v_d \Delta t$ on average
  - If wire's x-sectional area is A, in time Δt electrons in a volume $V = lA = Av_d\Delta t$ will pass through the area A
  - If there are n free electrons (of charge –e) per unit volume, the total charge ΔQ that pass through A in time Δt is
  - $\Delta Q = (\text{total number of charge, N}) \times (\text{charge per particle}) = (nV)(-e) = -(nAv_d \Delta t e)$
  - The current I in the wire is $I = \frac{\Delta Q}{\Delta t} = -neAv_d$
  - The density in vector form is $\vec{j} = \frac{I}{A} = -ne\vec{v}_d$
  - For any types of charge: $I = \sum_i n_i q_i v_{di} A$ $\quad$ $\vec{j} = \sum_i n_i q_i \vec{v}_{di}$

Microscopic View of Electric Current

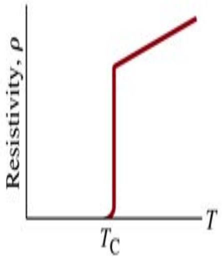
- The drift velocity of electrons in a wire is only about 0.05mm/s. How could we get light turned on immediately then?
  - While the electrons in a wire travels slow, the electric field travels essentially at the speed of light. Then what is all the talk about electrons flowing through?
    - It is just like water. When you turn on the facet, water flows right off the facet despite the fact that the water travels slow.
    - Electricity is the same. Electrons fill the conductor wire and when the switch is flipped on or a potential difference is applied, the electrons closed to the positive terminal flows into the bulb.
    - Interesting, isn't it? Why is the field travel at the speed of light then?

Ohm's Law in Microscopic View

- Ohm's law can be written in microscopic quantities.
  - Resistance in terms of resistivity is $R=\rho\frac{l}{A}$
  - We can rewirte V and I as: I=jA, V=El.
  - If electric field is uniform, from V=IR, we obtain
  - $V=IR$
  - $El=(jA)\left(\rho\frac{l}{A}\right)=j\rho l$
  - So $j=\frac{E}{\rho}=\sigma E$
  -
  - In a metal conductor, ρ or σ does not depend on V, thus, the current density j is proportional to the electric field E ➔ Microscopic statement of Ohm's Law
  - In vector form, the density can be written as $\vec{j}=\frac{\vec{E}}{\rho}=\sigma\vec{E}$

Superconductivity

- At the temperature near absolute 0K, resistivity of certain material becomes 0.
  - This state is called the "superconducting" state.
  - Observed in 1911 by H. K. Onnes when he cooled mercury to 4.2K (-269°C).
    - Resistance of mercury suddenly dropped to 0.
  - In general superconducting materials become superconducting below a transition temperature.



  - The highest temperature superconductivity seen is 160K
    - First observation above the boiling temperature of liquid nitrogen is in 1987 at 90k observed from a compound of yttrium, barium, copper and oxygen.
- Since much smaller amount of material can carry just as much current more efficiently, superconductivity can make electric cars more practical, computers faster, and capacitors store higher energy

Electric Hazards: Leakage Currents

- How does one feel shock by electricity?
  - Electric current stimulates nerves and muscles, and we feel a shock
  - The severity of the shock depends on the amount of current, how long it acts and through what part of the body it passes
  - Electric current heats tissues and can cause burns
- Currents above 70mA on a torso for a second or more is fatal, causing heart to function irregularly, “ventricular fibrillation”
- A dry human body between two points on opposite side of the body is about 10^4 to 10^6 Ω.
- When wet, it could be $10^3\Omega$.
- A person in good contact with the ground who touches 120V DC line with wet hands can get the current: $I=\frac{V}{R}=\frac{120V}{1000\Omega}=120mA$
  - Could be lethal