PHYS 1444 – Section 003
Lecture #11

Wednesday, Oct. 5, 2005
Dr. Jaehoon Yu

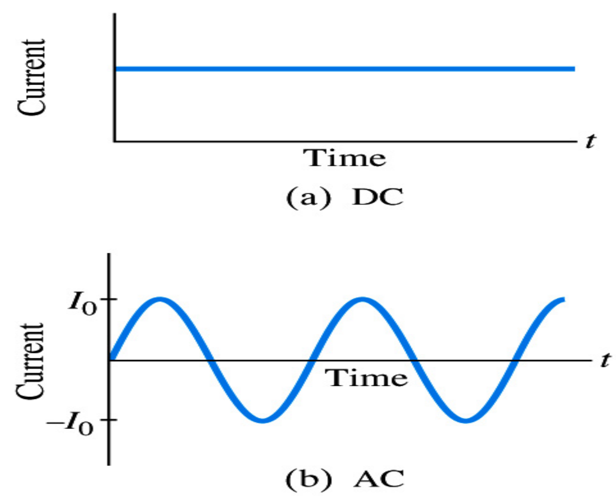
- Alternating Current (AC)
- Power in AC
- Microscopic view of current
- Superconductivity
- Electric shock hazards
- EMF and Terminal Voltage

Announcements

- Homework due has been changed to noon Tuesdays starting #6
- First term exam next Wednesday, Oct. 12
  - Time: 1 – 2:20 pm
  - Location: SH103
  - Coverage: CH. 21 – 25
- Reading Assignments
  - CH25 – 9
  - CH25 – 10
- There will be a workshop 1 – 5pm this Saturday in SH103 for construction of the World's Largest Cloud Chamber
  - Food from 12:30pm

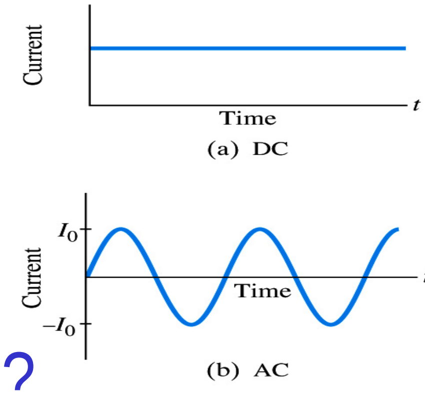
Alternating Current

- Does the direction of the flow of current change when a battery is connected to a circuit?
  - No. Why?
    - Because its source of potential difference stays put.
  - This kind of current is called the Direct Current (DC), and it does not change its direction of flow.
    - How would DC look as a function of time?
      - A straight line
- Electric generators at electric power plant produce alternating current (AC)
  - AC reverses direction many times a second
  - AC is sinusoidal as a function of time
- Most the currents supplied to homes and business are AC.



Alternating Current

- The voltage produced by an AC electric generator is sinusoidal
  - This is why the current is sinusoidal



- Voltage produced can be written as

$$V = V_0 \sin 2\pi ft = V_0 \sin \varpi t$$

- What are the maximum and minimum voltages?
  - V_0 and $-V_0$
  - The potential oscillates between $+V_0$ and $-V_0$, the peak voltages or amplitude
  - What is f?
    - The frequency, the number of complete oscillations made per second. What is the unit of f? What is the normal size of f in the US?
      - f=60Hz in the US and Canada.
      - Many European countries have f=50Hz.
  - $\omega = 2\pi f$

Alternating Current

- Since V=IR, if a voltage V exists across a resistance R, the current I is

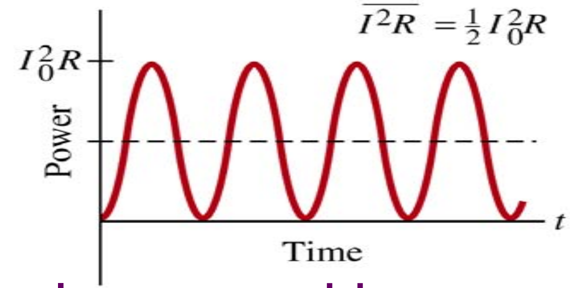
What is this?

$$I = \frac{V}{R} = \frac{V_0}{R}\sin 2\pi ft = I_0 \sin \varpi t$$

- What are the maximum and minimum currents?
  - I_0 and $-I_0$
  - The current oscillates between $+I_0$ and $-I_0$, the peak currents or amplitude. The current is positive when electron flows to one direction and negative when they flow opposite.
  - AC is as many times positive as negative. What's the average current?
    - Zero. So there is no power and no heat is produced in a heater?
      - Yes, the electrons actually flow back and forth and power is delivered.

Power Delivered by Alternating Current

- AC power delivered to a resistance is:



$$P = I^2R = I_0^2R\sin^2\varpi t$$

  – Since the current is squared, the power is always positive
- The average power delivered is $\bar{P} = \frac{1}{2}I_0^2R$
- Since the power is also P=V^2/R, we can obtain

$$P = \left(V_0^2/R\right)\sin^2\varpi t$$

Average power

$$\bar{P} = \frac{1}{2}\left(\frac{V_0^2}{R}\right)$$

- The average of the square of current and voltage are important in calculating power: $\overline{I^2} = \frac{1}{2}I_0^2$ $\overline{V^2} = \frac{1}{2}V_0^2$

Power Delivered by Alternating Current

- The square root of each of these are called root-mean-square, or rms:

$$I_{rms} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0$$

$$V_{rms} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707 V_0$$

- rms values are sometimes called effective values
  - These are useful quantities since they can substitute current and voltage directly in power, as if they are in DC

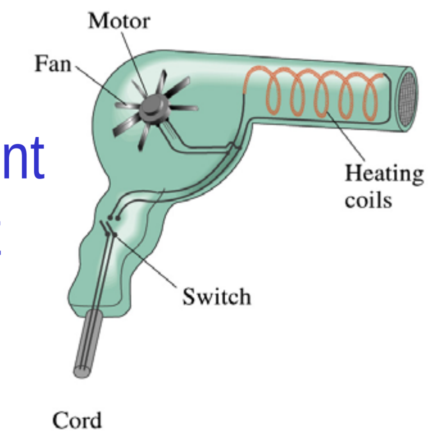
$$\overline{P} = \frac{1}{2} I_0^2 R = I_{rms}^2 R$$

$$\overline{P} = \frac{1}{2} \frac{V_0^2}{R} = \frac{V_{rms}^2}{R}$$

$$\overline{P} = I_{rms} V_{rms}$$

  - In other words, an AC of peak voltage V_0 or peak current I_0 produces as much power as DC voltage of V_{rms} or DC current I_{rms}.
  - So normally, rms values are specified in AC are specified or measured.
    - US uses 115V rms voltage. What is the peak voltage?
    - $V_0 = \sqrt{2} V_{rms} = \sqrt{2} \cdot 115V = 162.6V$
    - Europe uses 240V
    - $V_0 = \sqrt{2} V_{rms} = \sqrt{2} \cdot 240V = 340V$

Example 25 – 11



Hair Dryer. (a) Calculate the resistance and the peak current in a 1000-W hair dryer connected to a 120-V line. (b) What happens if it is connected to a 240-V line in Britain?

The rms current is: $I_{rms} = \frac{\overline{P}}{V_{rms}} = \frac{1000W}{120V} = 8.33A$

The peak current is: $I_0 = \sqrt{2} I_{rms} = \sqrt{2} \cdot 8.33A = 11.8A$

Thus the resistance is: $R = \frac{\overline{P}}{I_{rms}^2} = \frac{1000W}{(8.33A)^2} = 14.4\Omega$

(b) If connected to 240V in Britain …

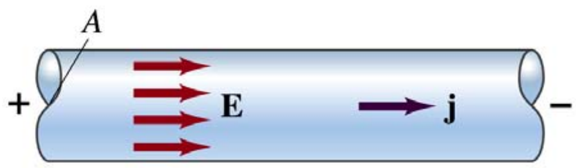
The average power provide by the AC in UK is

$$\overline{P} = \frac{V_{rms}^2}{R} = \frac{(240V)^2}{14.4\Omega} = 4000W$$

So? The heating coils in the dryer will melt!

Microscopic View of Electric Current

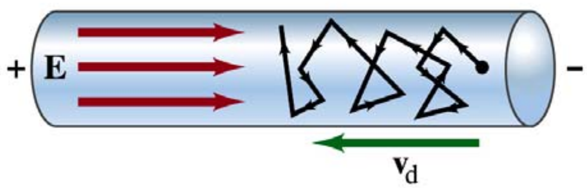
- When a potential difference is applied to the two ends of a wire of uniform cross-section, the direction of electric field is parallel to the walls of the wire, this is possible since the charges are moving, electrodynamics
- Let's define a microscopic vector quantity, the current density, **j**, the 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 a 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 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

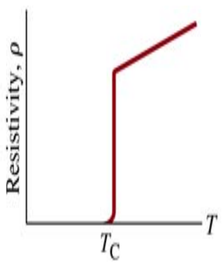
- The drift velocity of electrons in a wire is only about 0.05mm/s. How could we get light turned on immediately then?
  - While the electrons in a wire travels slow, the electric field travels essentially at the speed of light. Then what is all the talk about electrons flowing through?
    - It is just 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.
    - 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 rewire 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 $\vec{j} = \frac{\vec{E}}{\rho} = \sigma \vec{E}$

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