PHYS 1441 – Section 001
Lecture #11

Wednesday, June 20, 2018

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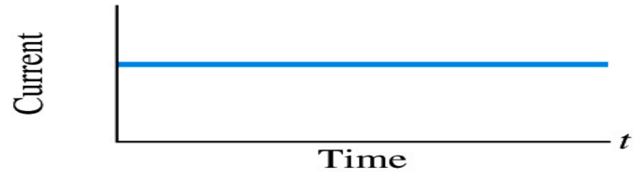
- Chapter 25
  - Alternating Current
  - Microscopic View of Electric Current
  - Ohm's Law in Microscopic View
  - EMF and Terminal Voltage

Announcements

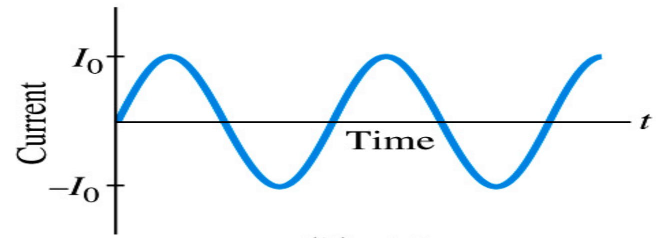
- Reading Assignments: CH25.8 - 25.10
- We will have a mid-term grade discussion Tuesday coming week, June 24. We will have a class for the first 30min followed by the discussion in my office.
- To allow the mid-term grade discussion, the date for term exam #2 will have to change to Thursday, June 28, from Wednesday, June 27.

Alternating Current

- Does the direction of the flow of current change while 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 while the battery is connected.
    - 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.



(a) DC

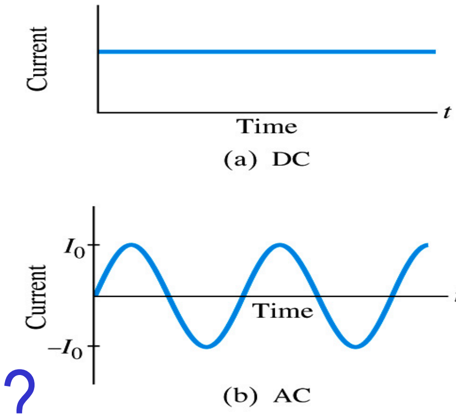


(b) AC

The 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

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



- What are the maximum and minimum voltages?
  - V_0 ($-V_0$) and 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

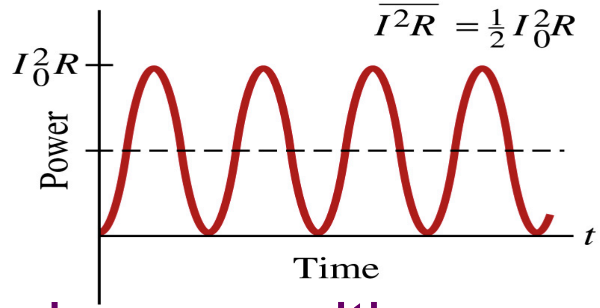
What is this?

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

- What are the maximum and minimum currents?
  - I_0 ($-I_0$) and 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 there is! The electrons actually flow back and forth, so power is delivered.

Power Delivered by Alternating Current

- AC power delivered to a resistance is:



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

  - Since the current is squared, the power is always positive
- The average power delivered is $\bar{P} = \frac{1}{2} I_0^2 R$
- 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

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

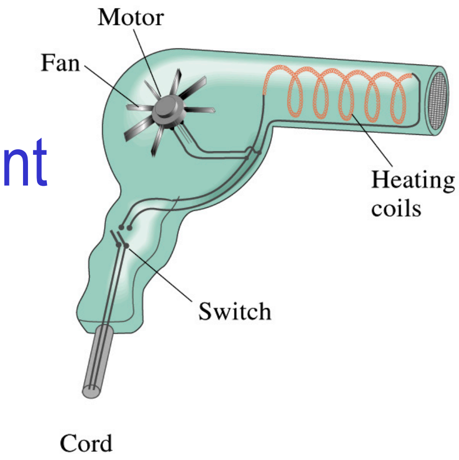
$$\overline{P} = \frac{1}{2} \frac{V_0^2}{R} = \frac{V_{rms}^2}{R}$$

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

  - 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 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 – 13

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



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

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

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

(b) If connected to 240V in Britain …

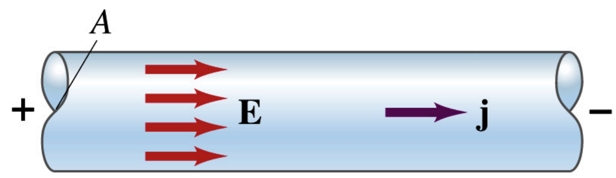
The average power provide by the AC in UK is

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

So? The heating coils in the dryer will melt!

Microscopic View of Electric Current

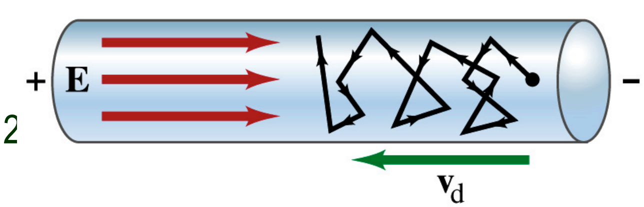
- When a potential difference is applied to the two ends of a wire w/ uniform cross-section, the direction of electric field is parallel to the walls of the wire, this is possible since the charges are moving
- Let's define a microscopic vector quantity, the current density, **j**, the electric current 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, $\mathbf{v}_d$
  - The drift velocity is normally much smaller than electrons' average random speed.



Microscopic View of Electric Current

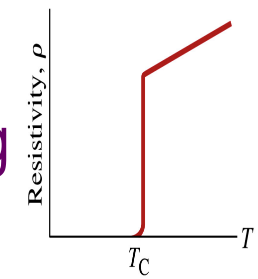
- The drift velocity of electrons in a wire is only about 0.05mm/s. How could we get light turned on immediately then?
  - While the electrons in a wire travels slow, the electric field travels essentially at the speed of light. Then what is all the talk about electrons flowing through?
    - It is just 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 close 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 rewrite the potential V and current 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 (T_c).
  - 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



Critical Temperature of Superconductors

Critical temperature (T_c), crystal structure and lattice constants of some high-T_c superconductors

Formula	Notation	T_c (K)	No. of Cu-O planes in unit cell	Crystal structure
$YBa_2Cu_3O_7$	123	92	2	Orthorhombic
$Bi_2Sr_2CuO_6$	Bi-2201	20	1	Tetragonal
$Bi_2Sr_2CaCu_2O_8$	Bi-2212	85	2	Tetragonal
$Bi_2Sr_2Ca_2Cu_3O_{10}$	Bi-2223	110	3	Tetragonal
$Tl_2Ba_2CuO_6$	Tl-2201	80	1	Tetragonal
$Tl_2Ba_2CaCu_2O_8$	Tl-2212	108	2	Tetragonal
$Tl_2Ba_2Ca_2Cu_3O_{10}$	Tl-2223	125	3	Tetragonal
$TlBa_2Ca_3Cu_4O_{11}$	Tl-1234	122	4	Tetragonal
$HgBa_2CuO_4$	Hg-1201	94	1	Tetragonal
$HgBa_2CaCu_2O_6$	Hg-1212	128	2	Tetragonal
$HgBa_2Ca_2Cu_3O_8$	Hg-1223	134	3	Tetragonal

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 the tissue 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 10^3Ω.
- A person in good contact with the ground who touches 120V DC line with wet hands can get the current:
  - Could be lethal

$$I = \frac{V}{R} = \frac{120V}{1000\Omega} = 120mA$$