PHYS 1444 – Section 002
Lecture 14

Monday, Oct. 14, 2019

Dr. Jaehoon Yu

CH 25

- Electric Power
- Alternating Current
- Microscopic View of Electric Current
- Ohm’s Law in Microscopic View

CH 26

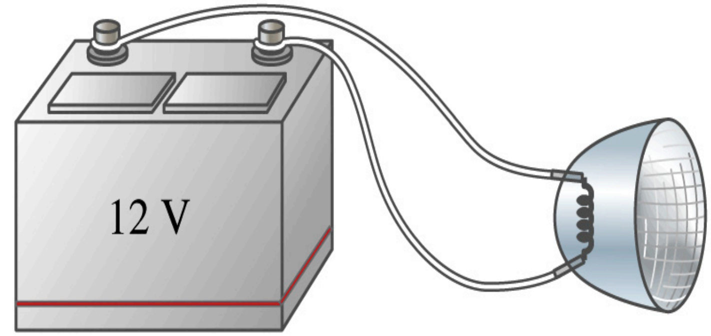
- EMF and Terminal Voltage
- Resistors in Series and Parallel

Announcements

- Reading Assignments: CH25.9 and 25.10
- Mid-term exam
  - This Wednesday, Oct. 16 in class
  - Comprehensive exam which covers CH21.1 through what we cover in class today (CH26.1?) + the math refresher in A1 – A8
  - Bring your calculator but DO NOT input formula into it!
    - Cell phones or any types of computers cannot replace a calculator!
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the quiz
  - No derivations, word definitions, set ups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
- Mid-term grade discussions
  - From 12:00 – 2:30pm, Wednesday, Oct. 24 in my office (CPB342)
  - Last name starts with A – D (12 – 12:30), E– K (12:30 – 1), L – O (1 – 1:30), P – S (1:30 – 2:00), T – Z (2-2:30)
- Suspension of Colloquium extra credit until further notice, except for
  - The two triple extra credit ones on Oct. 30 and Nov. 13 still valid. Will have a special sign-in sheet.
  - You are welcomed and encouraged to attend the seminar

Example 25 – 8

Headlights: Calculate the resistance of a 40-W automobile headlight designed for 12V.



40-W Headlight

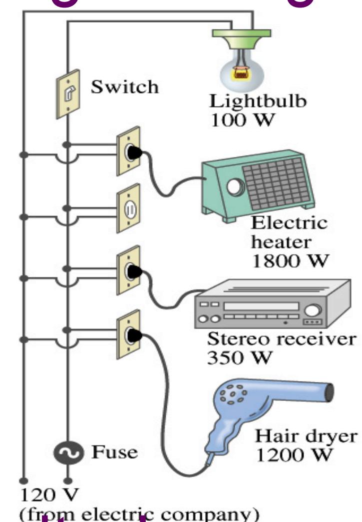
Since the power is 40W and the voltage is 12V, we use the formula with V and R.

$$\boxed{P = \frac{V^2}{R}} \quad \text{Solve for R} \Rightarrow \quad R = \frac{V^2}{P} = \frac{(12V)^2}{40W} = 3.6\Omega$$

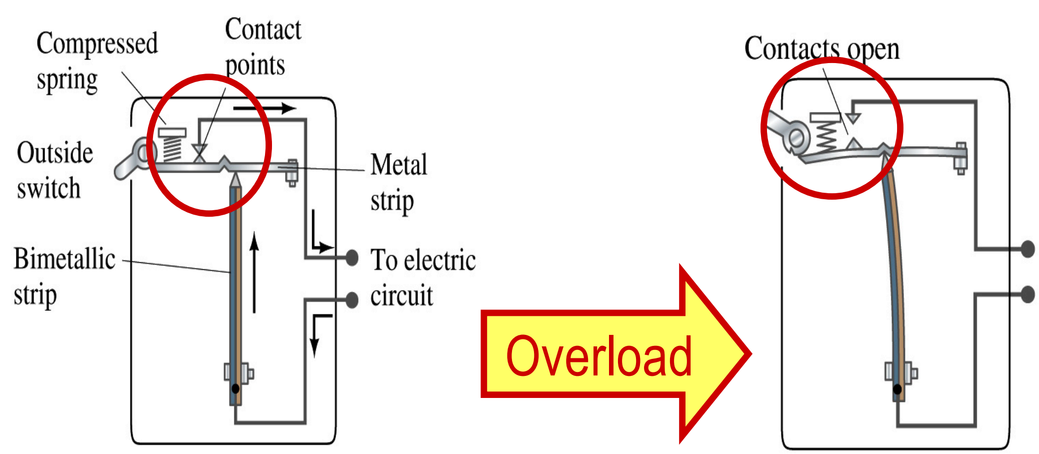
- What is the resistance of the filament of a 60W bulb?
- A 60W equivalent LED bulb draws 9.5W power. What is its resistance?
- A 100W equivalent LED bulb draws 17.5W power. What is its resistance?

Power in Household Circuits

- Household devices usually have small resistance
  - But since they draw current, if they become large enough, wires can heat up (overloaded)
    - Why is using thicker wires safer?
      - Thicker wires has less resistance, lower heat
  - Overloaded wire can set off a fire at home



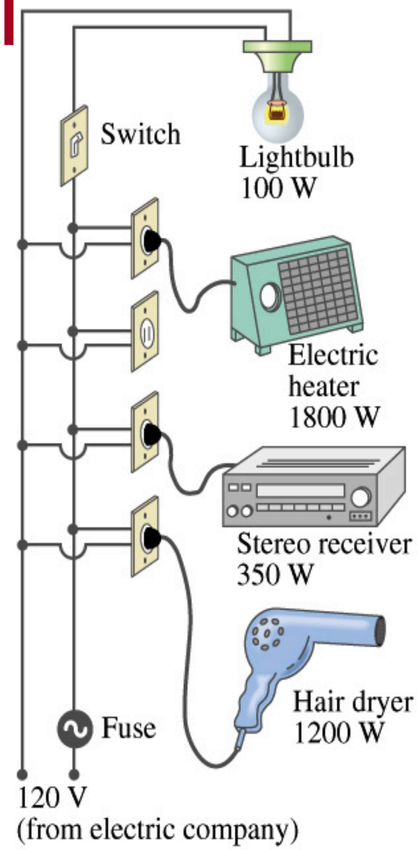
- How do we prevent this?
  - Put in a switch that would disconnect the circuit when overloaded
    - Fuse or circuit breakers
    - They open up the circuit when the current is over certain value



(b) Circuit breaker (closed)

(c) Circuit breaker (open)

Example 25 – 11



Will a fuse blow?: Determine the total current drawn by all the devices in the circuit in the figure. Will a 20A breaker trip if all devices are on?

The total current is the sum of current drawn by individual device.

$$P = IV$$ Solve for I $$I = P/V$$

Bulb $I_B = 100W/120V = 0.8A$

Heater $I_H = 1800W/120V = 15.0A$

Stereo $I_S = 135W/120V = 2.9A$

Dryer $I_D = 1200W/120V = 10.0A$

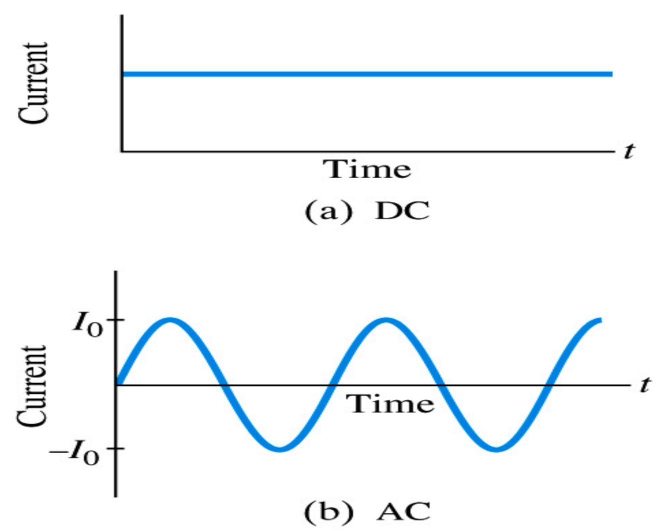
Total current

$$I_T = I_B + I_H + I_S + I_D = 0.8A + 15.0A + 2.9A + 10.0A = 28.7A$$

What is the total power? $P_T = P_B + P_H + P_S + P_D = 100W + 1800W + 350W + 1200W = 3450W$

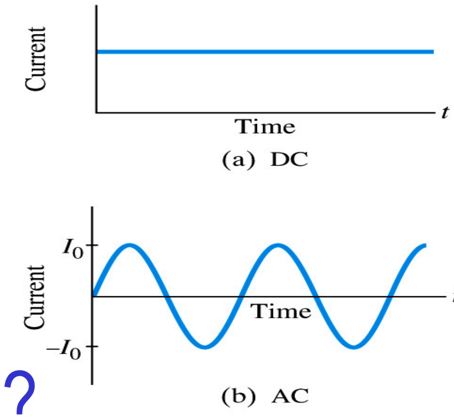
Alternating Current

- 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 current look as a function of time?
      - Straight lines
- The 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.



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

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

- What are the maximum and minimum voltages?
  - V_0 ($-V_0$) and 0
  - The potential oscillates between $+V_0$ and $-V_0$, the peak voltage or the 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

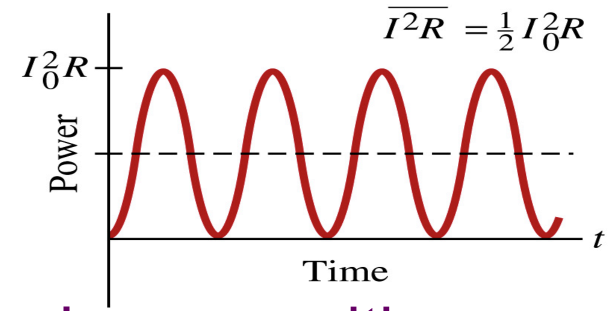
- Since V=IR, if a voltage V exists across a resistance R, the current I is

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 the amplitude. The current is positive when electron flows to one direction and negative when they flow the 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 $\overline{P} = \frac{1}{2} I_0^2 R$
- Since the power is also $P=V^2/R$, we can obtain

$$P = \left(V_0^2/R\right)\sin^2 \varpi t \quad \xrightarrow{\text{Average power}} \quad \overline{P} = \frac{1}{2}\left(\frac{V_0^2}{R}\right)$$

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

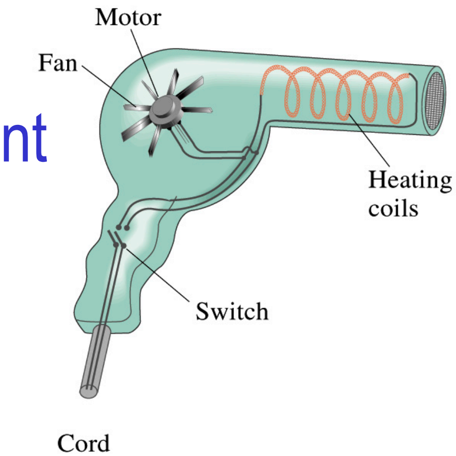
Power Delivered by Alternating Current

- The square root of each of these are called root-mean-square, or rms: $\boxed{I_{rms} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0}$ $\boxed{V_{rms} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707 V_0}$
- rms values are called the effective values
  - These are useful quantities since they can substitute current and voltage directly in power, as if they are in DC

$$\boxed{\overline{P} = \frac{1}{2} I_0^2 R = I_{rms}^2 R} \quad \boxed{\overline{P} = \frac{1}{2} \frac{V_0^2}{R} = \frac{V_{rms}^2}{R}} \quad \boxed{\overline{P} = I_{rms} V_{rms}}$$

  - 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 …

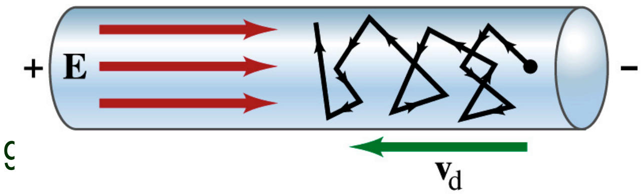
The average power provide by the AC in UK is

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

So? The heating coils in the dryer will melt!

Microscopic View of Electric Current

- When voltage is applied across the ends 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.

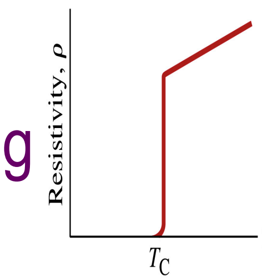


Microscopic View of Electric Current

- 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 travel 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 device.
    - Interesting, isn't it? Why is the field travel at the speed of light then?

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). ➔ 1913 Nobel physics prize
    - 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 $10^3\Omega$.
- A person in good contact with the ground who touches 120V DC line with wet hands can get the current:
  - Could be lethal

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