PHYS 1442 – Section 001
Lecture #7

Thursday, June 13, 2013
Dr. Jaehoon Yu

- Chapter 18
  - Electric Power
  - Alternating Current
  - Power Delivered by AC
  - Microscopic View of Electric Current
  - Ohm's Law in Microscopic View
  - Superconductivity
- Chapter 19
  - EMF and Terminal Voltage
  - Resistors in Series and Parallel

Today's homework is homework #4, due 11pm, Tuesday, June 18!!

Announcements

- Term exam results
  - Class average: 48.5/92
    - Equivalent to 52.7/100
  - Top score: 76/92
  - Remember this exam is 12% and can be replaced by the next term exam!
  - Homework takes the largest portion of the grade at 25%!
  - Mid term (20%) and final exams (23%) will be comprehensive!
- Second quiz, Monday, June 17
  - Covers CH17.9 through what we finish today (CH19.2?)
- Mid-term exam
  - Wednesday, June 19
  - Comprehensive exam
    - Covers CH16.1 – what we finish Tuesday, June 18 plus Appendices A1 – A8
- Quest payment of $25 each
  - Deadline is June 14.
  - If not paid, your homework access will be disabled.

Special Project #3

- Make a list of the power consumption and the resistance of all electric and electronic devices at your home and compiled them in a table. (5 points total for the first 10 items and 0.25 points each additional item.)
- Estimate the cost of electricity for each of the items on the table using your own electric cost per kWh (if you don't find your own, use $0.12/kWh) and put them in the relevant column. (2 points total for the first 10 items and 0.1 points each additional items)
- Estimate the the total amount of energy in Joules and the total electricity cost per day, per month and per year for your home. (6 points)
- Due: Beginning of the class Thursday, June 20

How does an electric heater work?

- Electrons flow through a circuit that includes the heater under a potential difference.
- Flowing electrons collide with the vibrating atoms in the wire.
- In each collision, part of electron's kinetic energy is transferred to the atom it collides with.
- The kinetic energy of wire's atoms increases, and thus the temperature of the wire increases.
- The increased thermal energy can be transferred as heat through conduction and convection to the air.
- So then what happens to the electrons that lost their kinetic energy?
  - Since they are still under potential difference, they will still flow to the other side of the electrode, gaining kinetic energy!

Electric Power

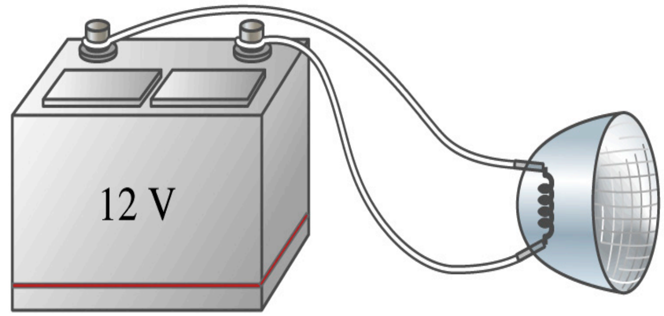
- Why is the electric energy useful?
  - It can transform into different forms of energy easily.
    - Motors, pumps, etc, transform electric energy to mechanical energy
    - Heaters, dryers, cook-tops, etc, transform electricity to thermal energy
    - Light bulb filament transforms electric energy to optical energy
      - Only about 10% of the energy turns to light and the 90% lost via heat
      - Typical household light bulb and heating elements have resistance of order few ohms to few hundred of ohms
- How does the electric energy transforms to thermal energy (toaster)?
  - Flowing electrons collide with the vibrating atoms of the wire.
  - In each collision, part of electron's kinetic energy is transferred to the atom it collides with.
  - The kinetic energy of wire's atoms increases, and thus the temperature of the wire increases.
  - The increased thermal energy can be transferred as heat through conduction and convection to the air in a heater or to food on a pan, through radiation to bread in a toaster or radiated as light.

Electric Power

- How do we find out the power transformed by an electric device?
  - What is definition of power?
    - The rate at which the work is done or the energy is transformed
- What is the energy transformed when an infinitesimal charge Δq moves through a potential difference V?
  - $\Delta U = V\Delta q$
  - If Δt is the time required for an amount of charge Δq to move through the potential difference V, the power P is
  - $P = \Delta U / \Delta t = V \Delta q / \Delta t$ **What is this?**
  - Thus, we obtain $\boxed{P = VI}$. **In terms of resistance** $\boxed{P = I^2 R = \frac{V^2}{R}}$
  - What is the unit? **Watts = J/s**
  - What kind of quantity is the electrical power?
    - Scalar
  - P=IV can apply to any devices while the formula with resistance can only apply to resistors.

Example 18 – 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.

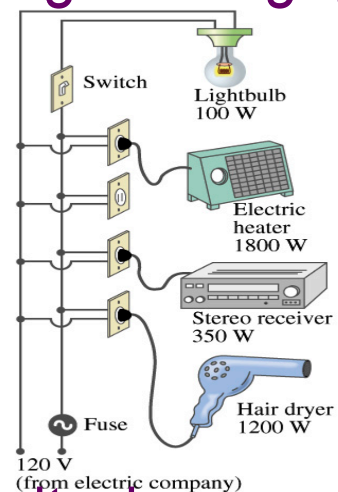
$$\boxed{P = \frac{V^2}{R}}$$

Solve for R

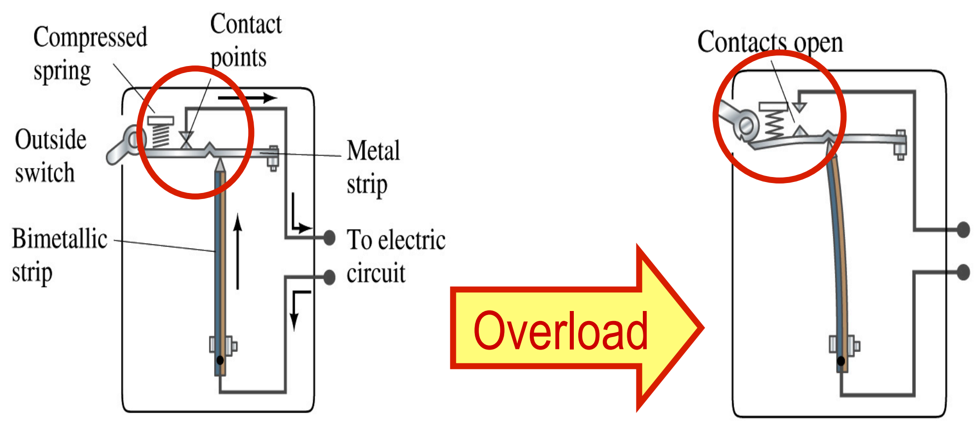
$$R = \frac{V^2}{P} = \frac{(12V)^2}{40W} = 3.6\Omega$$

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 have 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

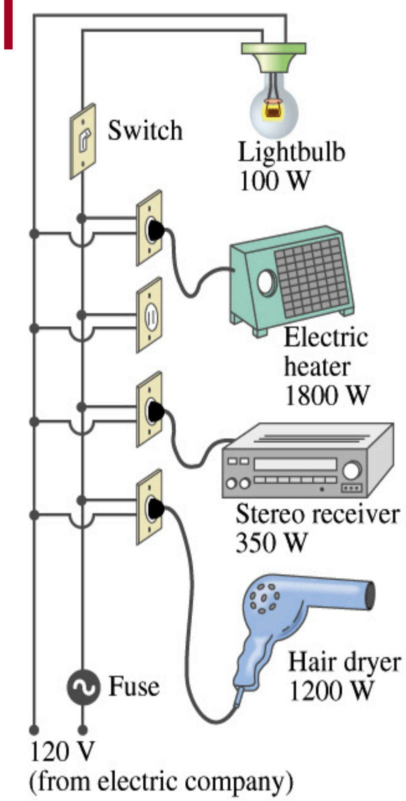


(b) Circuit breaker (closed)

(c) Circuit breaker (open)

Example 18 – 11

Will the fuse blow?: Calculate Determine the total current drawn by all the devices in the circuit in the figure.



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

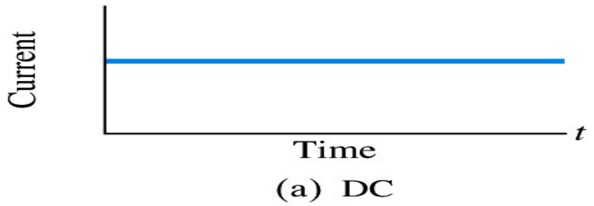
Total current

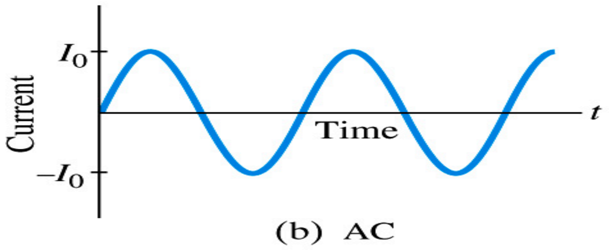
$$I_T = I_B + I_H + I_S + I_D = 0.8A + 15.0A + 2.9A + 10.0A = 28.7A$$

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 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.

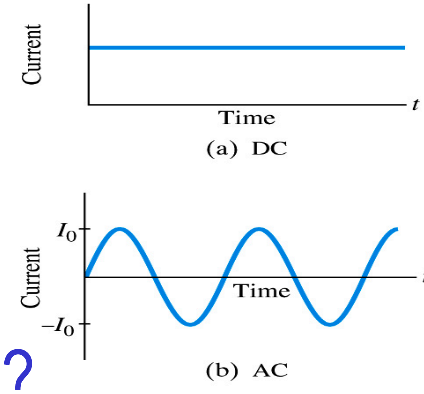




Alternating Current

- 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 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 (1/sec) in the US and Canada.
      - Many European countries have f=50Hz.
  - $\omega=2\pi f$

Alternating Current

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

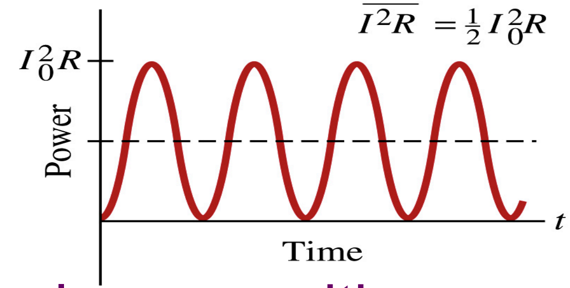
What is this?

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

- 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 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: $\overline{I^2} = \frac{1}{2} I_0^2$ $\quad \overline{V^2} = \frac{1}{2} V_0^2$

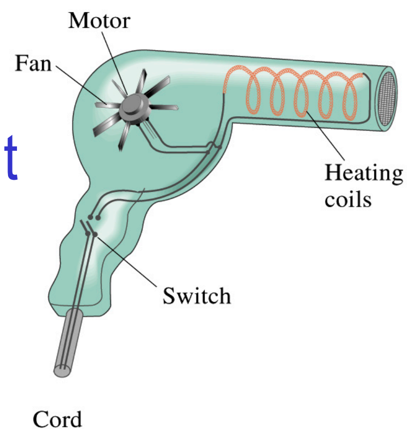
Power Delivered by Alternating Current

- The square root of each of these are called root-mean-square, or rms: $\boxed{I_{rms}=\sqrt{\overline{I^2}}=\frac{I_0}{\sqrt{2}}=0.707I_0}$ $\boxed{V_{rms}=\sqrt{\overline{V^2}}=\frac{V_0}{\sqrt{2}}=0.707V_0}$
- 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

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

  - In other words, an AC of peak voltage V_0 or peak current I_0 produces as much power as DC voltage 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 18 – 12



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 …

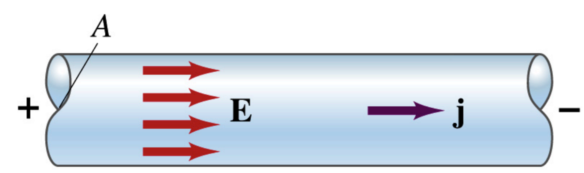
The average power provide by the AC in UK is

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

So? The heating coils in the dryer will melt!

Microscopic View of Electric Current

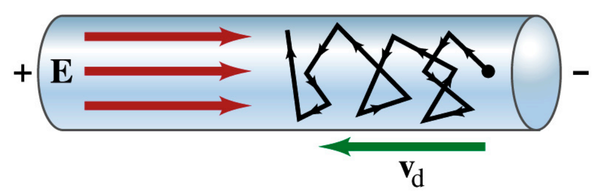
- When a potential difference is applied to the two ends of a wire w/ a uniform cross-section, the direction of the electric field is parallel to the walls of the wire, this is possible since the charges are moving
- Let's define a microscopic vector quantity, the current density **j**, the electric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



- The current density exists on any point in space while the current I refers to a conductor as a whole so it's 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 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 velocity due to collisions with atoms in the wire, called drift velocity, $\mathbf{v}_d$
  - The drift velocity is normally much smaller than the 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 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 rewrite 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
  - $\boxed{j = \frac{E}{\rho} = \sigma E}$
  - 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 $\boxed{\vec{j} = \frac{\vec{E}}{\rho} = \sigma \vec{E}}$