PHYS 1444 – Section 003
Lecture #13

Tuesday, Oct. 11, 2011

Dr. Jaehoon Yu

- Temperature Dependence of Resistance
- Electric Power
- Alternating Current
- Power Delivered by AC
- Microscopic View of Electric Current
- Ohm's Law in Microscopic View
- EMF and Terminal Voltage

Today's homework is #7, due 10pm, Tuesday, Oct. 18!!

Announcements

- Mid-Term Exam
  - Time and Date: 12:30 – 2pm, Thursday, Oct. 20 in SH103
  - Comprehensive Exam
    - Coverage: Ch. 21.1 – what we finish this Thursday plus Appendices A and B
  - There will be a review session Tuesday, Oct. 18, in class
    - Please bring your own problems
    - Attendance will be taken for extra credit
- Reading assignments
  - CH25. 8 – 25.10
- Colloquium tomorrow
  - 4pm in SH101

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Solving the Mystery of Weak Emission Line Quasars at High Redshift

Dr. Ohad Shemmer
University of North Texas

4:00p.m Wednesday October 12, 2011
Room 101 Science Hall

Abstract:

Since strong and broad emission lines are a hallmark of quasar UV spectra, the recent discovery of ~80 Sloan Digital Sky Survey quasars at z~2.2-5.9 with strong blue continua but extremely weak or undetectable emission lines is puzzling. I will present a step-by-step overview of multiwavelength observations that provided insights into the nature of these remarkable sources. In particular, I will show that the weakness of their emission lines is unlikely to be due to line absorption, dust obscuration, gravitational lensing or microlensing effects, or relativistic beaming. Finally, I will describe an observational and theoretical effort required to distinguish between two competing scenarios for the weakness of the emission lines in these sources. The results of this study will likely shed light not only on the nature of this rare class of quasars but also on emission-line formation in all active galactic nuclei.

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Refreshments will be served at 3:30 in the physics lounge

Special Project #4

- 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 for the first 10 items and 0.1 points each additional item.)
- Estimate the cost of electricity for each of the items on the table assuming the electricity cost is $0.12 per kWh and put them in a separate column in the above table. (2points for the first 10 items and 0.1 points each additional items)
- Estimate the total amount of energy in Joules and the total electricity cost per month and per year for your home. (4 points)
- Due: Beginning of the class Tuesday, Nov. 1

Temperature Dependence of Resistivity

- Do you think the resistivity depends on temperature?
  - Yes
- Would it increase or decrease with the temperature?
  - Increase
  - Why?
  - Because the atoms are vibrating more rapidly as temperature increases and are arranged in a less orderly fashion. So?
    - They might interfere more with the flow of electrons.
- If the temperature change is not too large, the resistivity of metals usually increase nearly linearly w/ temperature

$$\rho_T = \rho_0 \left[1 + \alpha \left(T - T_0 \right) \right]$$

  - α is the temperature coefficient of resistivity
  - α of some semiconductors can be negative due to increased number of freed electrons.

Electric Power

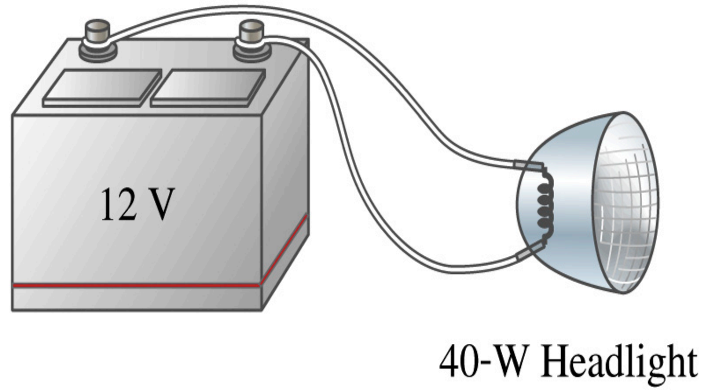
- Why is the electric energy useful?
  - It can transform into different forms of energy easily.
    - Motors, pumps, etc, transform electric energy to mechanical energy
    - Heaters, dryers, cook-tops, etc, transforms electricity to thermal energy
    - Light bulb filament transforms electric energy to light 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 a few ohms to a few hundred ohms
- How does electric energy transforms to thermal energy?
  - 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 the power?
    - The rate at which work is done or the energy is transformed
- What is the energy transformed when an infinitesimal charge dq moves through a potential difference V?
  - dU=Vdq
  - If dt is the time required for an amount of charge dq to move through the potential difference V, the power P is
  - $P = dU/dt = V dq/dt$ **What is this?**
  - Thus, we obtain $P = VI$. **In terms of resistance** $P = I^2 R = \frac{V^2}{R}$
  - 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 25 – 8

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



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

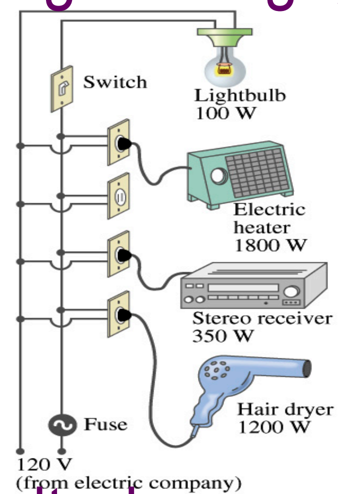
$$P = \frac{V^2}{R}$$

Solve for R

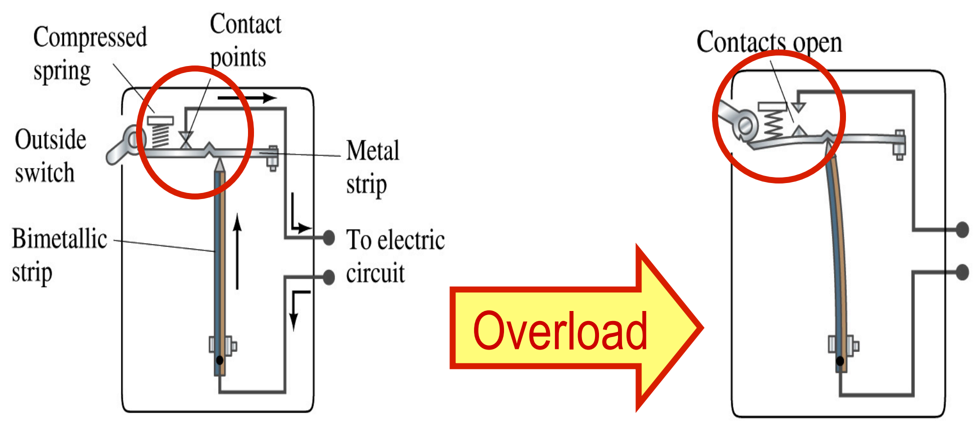
$$R = \frac{V^2}{P} = \frac{(12V)^2}{40W} = 3.6\Omega$$

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 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

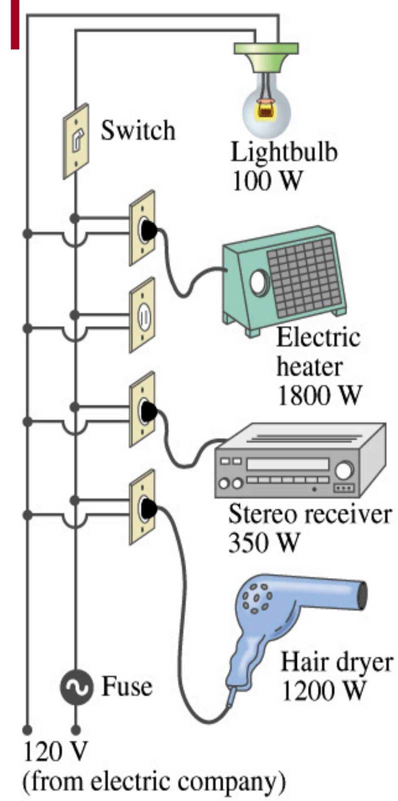


(b) Circuit breaker (closed)

(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.



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

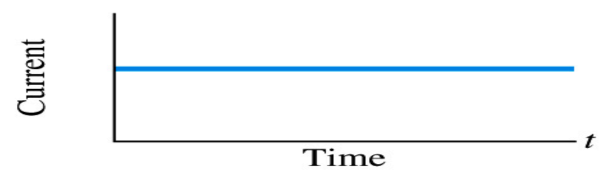
Total current

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

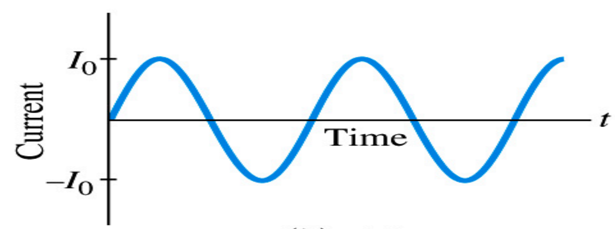
What is the total power? $P_T = P_B + P_H + P_S + P_D = 100W + 1800W + 350W + 1200W = 3450W$

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 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.



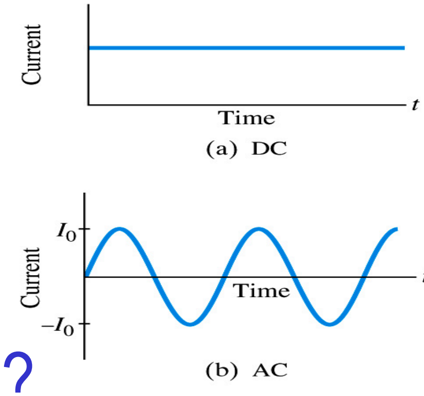
(a) DC



(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



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

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

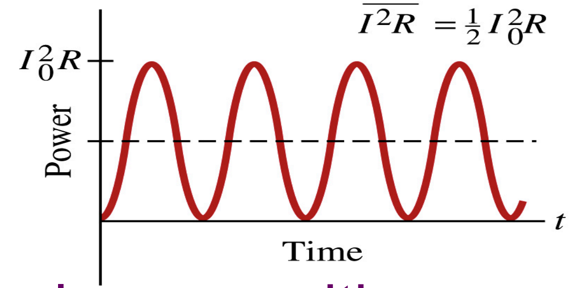
What is this?

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

- 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:



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

  – Since the current is squared, the power is always positive

- The average power delivered is $\overline{P} = \frac{1}{2}I_0^2R$
- Since the power is also P=V²/R, we can obtain

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

Average power

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

- 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:

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

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

- 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

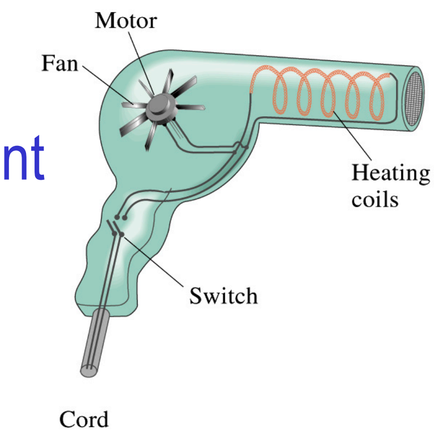
$$\overline{P} = \frac{1}{2} I_0^2 R = I_{rms}^2 R$$

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

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

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

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 …

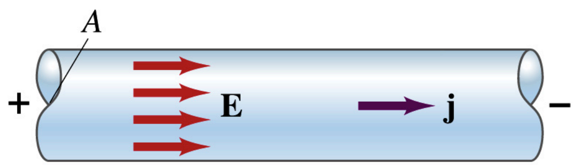
The average power provide by the AC in UK is

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

So? The heating coils in the dryer will melt!

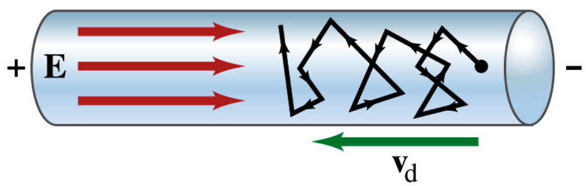
Microscopic View of Electric Current

- When a potential difference is applied to the two ends of a wire 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

- 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
  - $\Delta Q = (\text{total number of charge, N}) \times (\text{charge per particle}) = (nV)(-e) = -(nAv_d \Delta te)$
  - 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

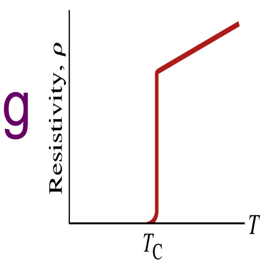
- The drift velocity of electrons in a wire is only about 0.05mm/s. How could we get light turned on immediately then?
  - While the electrons in a wire travels slow, the electric field travels essentially at the speed of light. Then what is all the talk about electrons flowing through?
    - It is just 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 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^{o}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 W.
- When wet, it could be 10^3W.
- A person in good contact with the ground who touches 120V DC line with wet hands can get the current:
  - Could be lethal

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