

PHYS 1444 – Section 003

Lecture #10

Monday, Oct. 3, 2005

Dr. Jaehoon Yu

- Electric Current
- Ohm's Law: Resistance and Resistor
- Resistivity
- Electric Power
- Power in Household Circuits

Today's homework is homework #6, due noon, next Tuesday!!



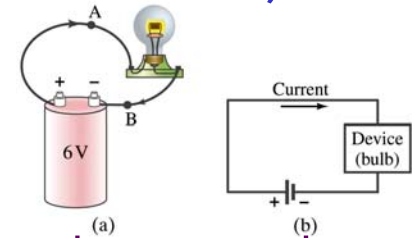
Announcements

- First term exam next Wednesday, Oct. 12
 - Time: 1 – 2:20 pm
 - Location: SH103
 - Coverage: CH. 21 – 25
 - Style: Mixture of multiple choice and numeric problems
 - There will be two more exams
 - Monday, Nov. 7, and Monday, Dec. 5
 - Two best of the three will be chosen for your final grading
- Reading Assignment
 - CH25 – 6



Electric Current

- When a circuit is powered by a battery (or a source of emf) the charge can flow through the circuit.
- Electric Current: Any flow of charge
 - Current can flow whenever there is potential difference between the ends of a conductor (or when the two ends have opposite charges)
 - The current can flow even through the empty space
 - Electric current in a wire can be defined as the net amount charge that passes through the wire's full cross section at any point per unit time (just like the flow of water through a conduit..)
 - Average current is defined as: $\bar{I} = \Delta Q / \Delta t$
 - The instantaneous current is: $I = dQ / dt$
 - What kind of a quantity is the current?



Unit of the current?

C/s

1A=1C/s

Scalar

In a single circuit, conservation of electric charge guarantees that the current at one point of the circuit is the same as any other points on the circuit.

Example 25 – 1

Current is the flow of charge: A steady current of 2.5A flows in a wire for 4.0min. (a) How much charge passed by any point in the circuit? (b) How many electrons would this be?

Current is total amount charge flow through a circuit in a given time. So from $\Delta Q = I \Delta t$ we obtain

$$\Delta Q = I \Delta t = 2.5 \times 4.0 \times 60 = 600C$$

The total number of electrons passed through the circuit is

$$N_e = \frac{\Delta Q}{e} = \frac{600C}{1.6 \times 10^{-19} C} = 3.8 \times 10^{21} \text{ electrons}$$



Direction of the Electric Current

- What do conductors have in abundance?
 - Free electrons
- What happens if a continuous loop of conducting wire is connected to the terminals of the battery?
 - Electrons start flow of through the wire continuously as soon as both the terminals are connected to the wire. How?
 - The potential difference between the battery terminals sets up an electric field inside the wire and parallel to it
 - Free electrons in the conducting wire get attracted to the positive terminal
 - The electrons leaving negative terminal flow through the wire and arrive at the positive terminal
 - Electrons flow from negative to positive terminal
 - Due to historical convention, the direction of the current is opposite to the direction of flow of electrons ➔ Conventional Current



Ohm's Law: Resistance and Resistors

- What do we need to produce electric current?
 - Potential difference
- Georg S. Ohm experimentally established that the current is proportional to the potential difference ($I \propto V$)
 - If we connect a wire to a 12V battery, the current flowing through the wire is twice that of 6V, three times that of 4V and four times that of 3V battery.
 - What happens if we reverse the sign of the voltage?
 - It changes the direction of the current flow
 - Does not change the magnitude of the current
 - Just as in water flow case, if the height difference is large the flow rate is large → If the potential difference is large, the current is large.



Ohm's Law: Resistance

- The exact amount of current flow in a wire depends on
 - The voltage
 - The resistance of the wire to the flow of electrons
 - Just like gunk in water pipe slows down water flow
 - Electrons are slowed down due to interactions with the atoms of the wire
- The higher the resistance the less the current for the given potential difference V
 - So how would you define resistance?
 - So that current is inversely proportional to the resistance
 - Often it is rewritten as $V = IR$ Ohm's Law
 - What does this mean?
 - The metal conductor's resistance R is a constant independent of V .
 - This linear relationship is not valid for some materials like diodes, vacuum tubes, transistors etc. → These are called non-ohmic

$$R = \frac{V}{I}$$

Unit?

ohms

Ω

$$1.0\Omega = 1.0V / A$$



Example 25 – 3

Flashlight bulb resistance: A small flashlight bulb draws 300mA from its 1.5V battery. (a) What is the resistance of the bulb? (b) If the voltage drops to 1.2V, how would the current change?

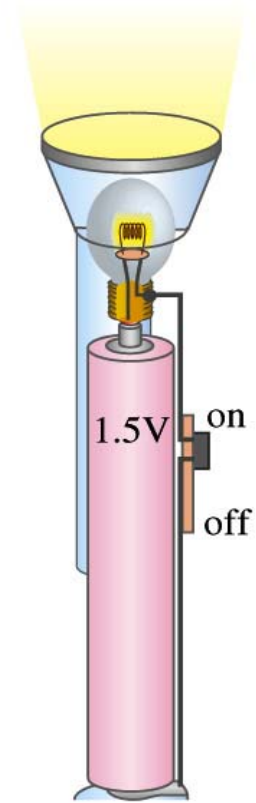
From Ohm's law, we obtain

$$R = \frac{V}{I} = \frac{1.5V}{300mA} = \frac{1.5V}{0.3A} = 5.0\Omega$$


Would the current increase or decrease, if the voltage reduces to 1.2V?

If the resistance did not change, the current is

$$I = \frac{V}{R} = \frac{1.2V}{5.0\Omega} = 0.24A = 240mA$$



Ohm's Law: Resistors

- All electric devices offer resistance to the flow of current.
 - Filaments of light bulbs or heaters are wires with high resistance to cause electrons to lose their energy in the wire
 - In general connecting wires have low resistance compared to other devices on the circuit
- In circuits, resistors are used to control the amount of current
 - Resistors offer resistance of less than one ohm to millions of ohms
 - Main types are
 - “wire-wound” resistors which consists of a coil of fine wire
 - “composition” resistors which are usually made of semiconductor carbon
 - thin metal films
- When drawn in the circuit, the symbol for a resistor is: 
- Wires are drawn simply as straight lines

Monday, Oct. 3, 2005



PHYS 1444-003, Fall 2005
Dr. Jaehoon Yu

Ohm's Law: Resistor Values

- Resistors have its resistance color-coded on its body
- The color-coding follows the convention below:

Color	Number	Multiplier	Tolerance
Black	0	$1=10^0$	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5%
Silver		10^{-2}	10%
None			20%



First digit
Second digit
Multiplier
Tolerance

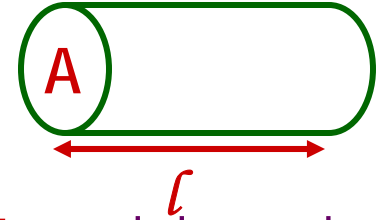
What is the resistance of the resistor in this figure?

$$25 \times 10^3 \pm 10\%$$

Resistivity

- It is experimentally found that the resistance R of a metal wire is directly proportional to its length l and inversely proportional to its cross-sectional area A

$$R = \rho \frac{l}{A}$$



- How would you formularize this?
- The proportionality constant ρ is called the resistivity and depends on the material used. What is the unit of this constant?
 - ohm-m or $\Omega\text{-m}$
 - The values depends on purity, heat treatment, temperature, etc
- How would you interpret the resistivity?
 - The higher the resistivity the higher the resistance
 - The lower the resistivity the lower the resistance and the higher the conductivity → Silver has the lowest resistivity.
 - So the silver is the best conductor
- The reciprocal of the resistivity is called the conductivity, σ ,

$$\sigma = \frac{1}{\rho}$$

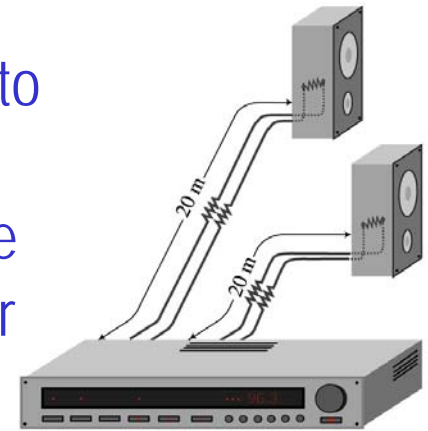
Monday, Oct. 3, 2005



PHYS 1444-003, Fall 2005
Dr. Jaehoon Yu

Example 25 – 4

Speaker wires: Suppose you want to connect your stereo to remote speakers. (a) If each wire must be 20m long, what diameter copper wire should you use to keep the resistance less than $0.1\text{-}\Omega$ per wire? (b) If the current on each speaker is 4.0A , what is the voltage drop across each wire?



The resistivity of a copper is $\rho_{Cu} = 1.68 \times 10^{-8} \Omega \cdot m$ Table 25.1

From the formula for resistance, we can obtain the formula for area

$$R = \rho \frac{l}{A} \quad \xrightarrow{\text{Solve for A}} \quad A = \rho \frac{l}{R} = \pi r^2$$

$$\xrightarrow{\text{Solve for d}} \quad d = 2r = 2\sqrt{\frac{\rho l}{\pi R}} = 2\sqrt{\frac{1.68 \times 10^{-8} \Omega \cdot m \cdot 20m}{\pi \cdot 0.1\Omega}} = 2.1 \times 10^{-3} m = 2.1 mm$$

From Ohm's law, $V=IR$, we obtain

$$V = IR = 4.0A \cdot 0.1\Omega = 0.4V$$

Example 25 – 5

Stretching changes resistance: A wire of resistance R is stretched uniformly until it is twice its original length. What happens to its resistance?

What is the constant quantity in this problem? The volume!

What is the volume of a cylinder of length L and radius r ? $V = AL = \pi r^2 L$

What happens to A if L increases factor two, $L' = 2L$?

The cross-sectional area, A , halves. $A' = A/2$

The original resistance is $R = \rho \frac{l}{A}$

The new resistance is $R' = \rho \frac{L'}{A'} = \rho \frac{2L}{A/2} = 4\rho \frac{L}{A} = 4R$

The resistance of the wire increases by a factor of four if the length increases twice.

Temperature Dependence of Resistivity

- Do you think the resistivity depends on temperature?
 - Yes
- Would it increase or decrease with the temperature?
 - Increase
 - Why?
 - Since 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
$$\rho_T = \rho_0 [1 + \alpha(T - T_0)]$$
 - 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 to 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 few ohms to few hundred of 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 by conduction and convection to the air in a heater or to food in a pan, by radiation to bread in a toaster or radiated as light.



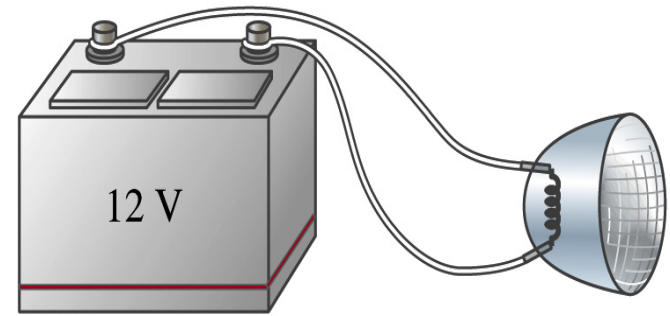
Electric Power

- 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
 - $P = dU/dt = Vdq/dt$ ← **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 – 7

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.

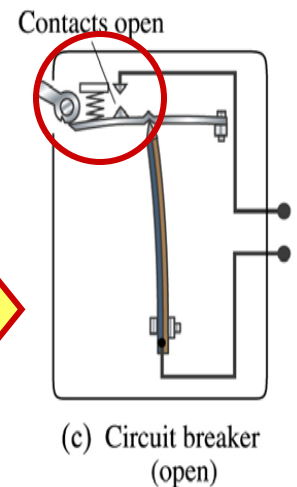
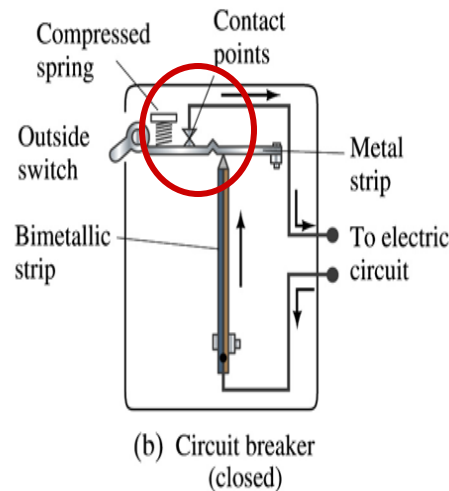
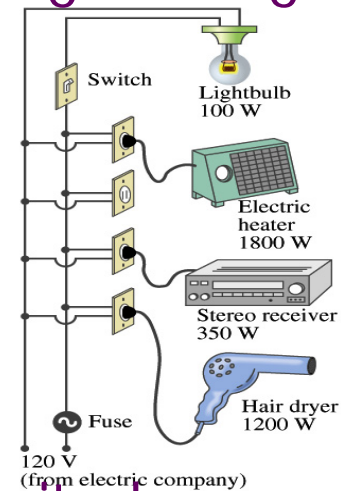
$$P = \frac{V^2}{R}$$

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

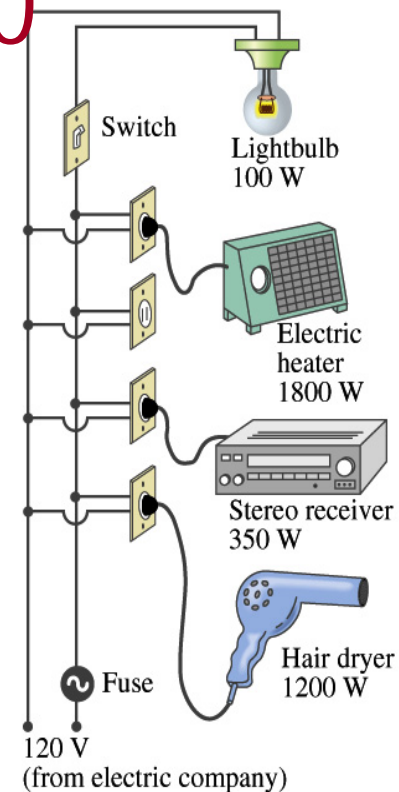


Example 25 – 10

Will a 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.

$$P = IV \quad \text{Solve for } I \quad I = P/V$$



Bulb $I_B = 100\text{W}/120\text{V} = 0.8\text{A}$

Heater $I_H = 1800\text{W}/120\text{V} = 15.0\text{A}$

Stereo $I_S = 350\text{W}/120\text{V} = 2.9\text{A}$

Dryer $I_D = 1200\text{W}/120\text{V} = 10.0\text{A}$

Total current

$$I_T = I_B + I_H + I_S + I_D = 0.8\text{A} + 15.0\text{A} + 2.9\text{A} + 10.0\text{A} = 28.7\text{A}$$

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