PHYS 1444 – Section 003
Lecture #14

Thursday, Oct. 13, 2011

Dr. Jaehoon Yu

- EMF and Terminal Voltage
- Resistors in Series and Parallel
- Energy losses in Resistors
- Kirchhoff's Rules
- RC Circuits

Announcements

- Mid-Term Exam
  - Time and Date: 12:30 – 2pm, Thursday, Oct. 20 in SH103
  - Comprehensive Exam
    - Coverage: Ch. 21.1 – CH26.3 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

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 for each additional item.)
  - What is an item?
    - Similar electric devices count as one item.
      - All light bulbs make up one item, computers another, refrigerators, TVs, dryers (hair and clothes), electric cooktops, heaters, microwave ovens, electric ovens, dishwashers, etc.
      - All you have to do is to count add all wattages of the light bulbs together as the power of the item
- Estimate the cost of electricity for each of the items on the table using your own electricity rate per kWh (specify this cost on the table) and put them in a separate column in the above table. (2 points for the first 10 items and 0.1 points for each additional item.)
- Estimate the 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 Thursday, Oct. 27

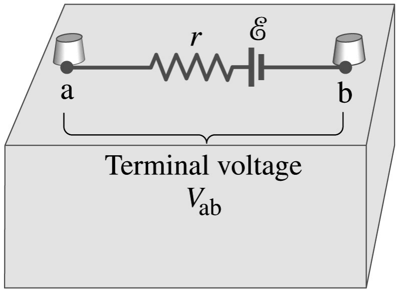
Electric Hazards: Leakage Currents

- 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 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: $I = \frac{V}{R} = \frac{120V}{1000\Omega} = 120mA$
  - Could be lethal

EMF and Terminal Voltage

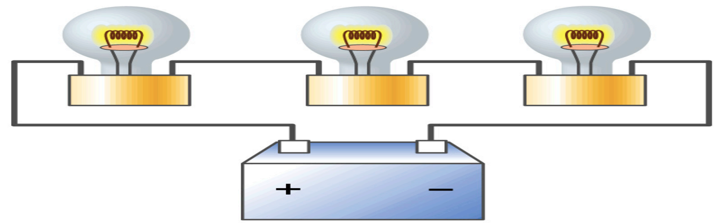
- What do we need to have current in an electric circuit?
  - A device that provides a potential difference, such as a battery or a generator
    - They normally convert some types of energy into the electric energy
    - These devices are called source of electromotive force (emf)
      - This is does NOT refer to a real "force".
- Potential difference between terminals of an emf source, when no current flows to an external circuit, is called the emf ($\mathcal{E}$) of the source.
- The battery itself has some **internal resistance** (r) due to the flow of charges in the electrolyte
  - Why does the headlight dim when you start the car?
    - The starter needs a large amount of current but the battery cannot provide charge fast enough to supply current to both the starter and the headlight

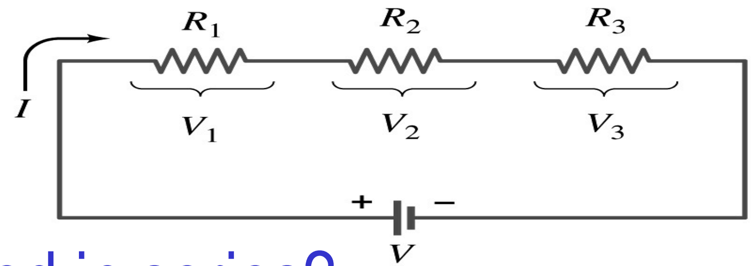
EMF and Terminal Voltage



- Since the internal resistance is inside the battery, we can never separate them out.
- So the terminal voltage difference is $V_{ab}=V_a-V_b$.
- When no current is drawn from the battery, the terminal voltage equals the emf which is determined by the chemical reaction; $V_{ab}=\mathcal{E}$.
- However when the current I flows naturally from the battery, there is an internal drop in voltage which is equal to Ir. Thus the actual **delivered** terminal voltage is $\boxed{V_{ab}=\varepsilon-Ir}$

Resisters in Series





- Resisters are in series when two or more resisters are connected end to end
  - These resisters represent simple resisters in circuit or electrical devices, such as light bulbs, heaters, dryers, etc
- What is common in a circuit connected in series?
  - Current is the same through all the elements in series
- Potential difference across every element in the circuit is
  - $V_1=IR_1$, $V_2=IR_2$ and $V_3=IR_3$
- Since the total potential difference is V, we obtain
  - $V=IR_{eq}=V_1+V_2+V_3=I(R_1+R_2+R_3)$
  - Thus, $R_{eq}=R_1+R_2+R_3$

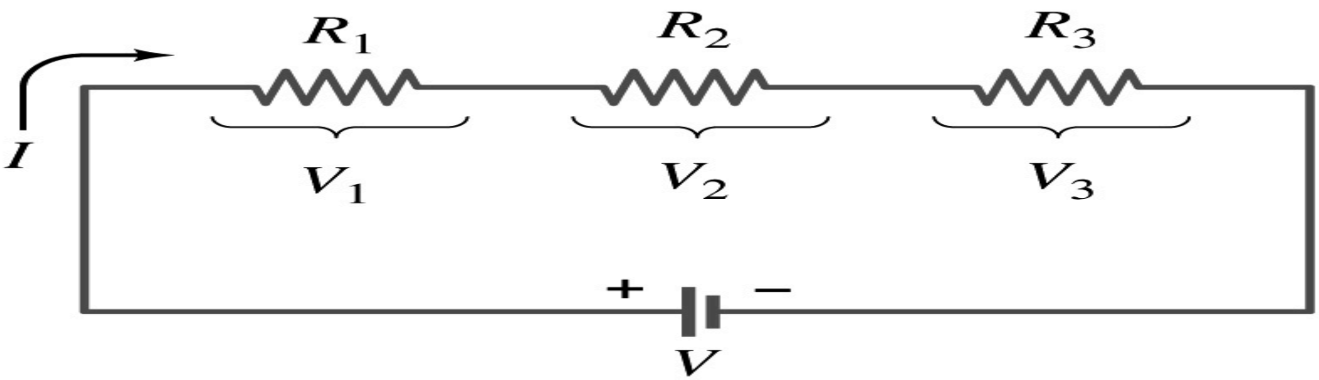
$$R_{eq} = \sum_i R_i$$

Resisters in series

When resisters are connected in series, the total resistance increases and the current decreases.

Energy Losses in Resisters

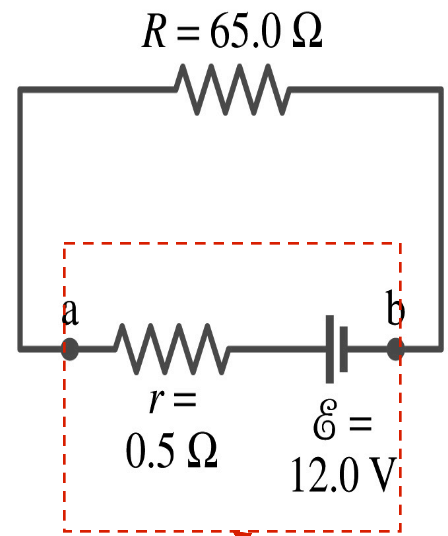
- Why is it true that $V=V_1+V_2+V_3$?



- What is the potential energy loss when charge q passes through resisters R_1, R_2 and R_3
  - $\Delta U_1=qV_1$, $\Delta U_2=qV_2$, $\Delta U_3=qV_3$
- Since the total energy loss should be the same as the total energy provided to the system, we obtain
  - $\Delta U=qV=\Delta U_1+\Delta U_2+\Delta U_3=q(V_1+V_2+V_3)$
  - Thus, $V=V_1+V_2+V_3$

Example 26 – 1

Battery with internal resistance. A 65.0-Ω resistor is connected to the terminals of a battery whose emf is 12.0V and whose internal resistance is 0.5-Ω. Calculate (a) the current in the circuit, (b) the terminal voltage of the battery, V_{ab}, and (c) the power dissipated in the resistor R and in the battery's internal resistor.



What is this?

A battery or a source of emf.

(a) Since $V_{ab}=\varepsilon-Ir$ We obtain $V_{ab}=IR=\varepsilon-Ir$

Solve for I

$$I=\frac{\varepsilon}{R+r}=\frac{12.0V}{65.0\Omega+0.5\Omega}=0.183A$$

(b) The terminal voltage V_{ab} is $V_{ab}=\varepsilon-Ir=12.0V-0.183A\cdot0.5\Omega=11.9V$

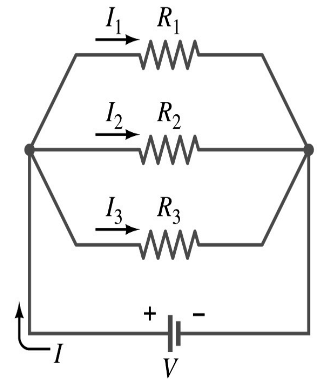
(c) The power dissipated in R and r are

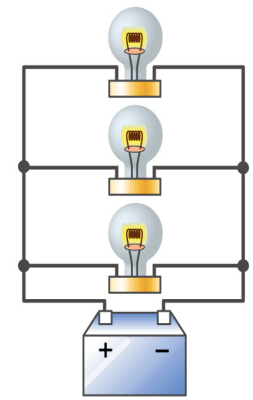
$$P=I^2R=(0.183A)^2\cdot65.0\Omega=2.18W$$

$$P=I^2r=(0.183A)^2\cdot0.5\Omega=0.02W$$

Resisters in Parallel

- Resisters are in parallel when two or more resisters are connected in separate branches
  - Most the house and building wirings are arranged this way.





- What is common in a circuit connected in parallel?
  - The voltage is the same across all the resisters.
  - The total current that leaves the battery, is however, split.
- The current that passes through every element is
  - $I_1=V/R_1$, $I_2=V/R_2$, $I_3=V/R_3$
- Since the total current is I, we obtain
  - $I=V/R_{eq}=I_1+I_2+I_3=V(1/R_1+1/R_2+1/R_3)$
  - Thus, $1/R_{eq}=1/R_1+1/R_2+1/R_3$

$$\boxed{\frac{1}{R_{eq}}=\sum_i \frac{1}{R_i}}$$

Resisters in parallel

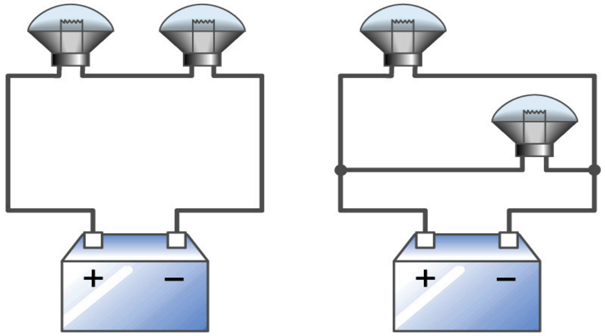
When resisters are connected in parallel, the total resistance decreases and the current increases.

Resister and Capacitor Arrangements

- Parallel Capacitor arrangements $$C_{eq} = \sum_i C_i$$
- Parallel Resister arrangements $$\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$$
- Series Capacitor arrangements $$\frac{1}{C_{eq}} = \sum_i \frac{1}{C_i}$$
- Series Resister arrangements $$R_{eq} = \sum_i R_i$$

Example 26 – 2

Series or parallel? (a) The light bulbs in the figure are identical and have identical resistance R. Which configuration produces more light? (b) Which way do you think the headlights of a car are wired?



(1) Series (2) Parallel

(a) What are the equivalent resistances for the two cases?

Series → $R_{eq} = 2R$

Parallel → $\frac{1}{R_{eq}} = \frac{2}{R}$ **So** → $R_{eq} = \frac{R}{2}$

The bulbs get brighter when the total power transformed is larger.

series $P_S = IV = \frac{V^2}{R_{eq}} = \frac{V^2}{2R}$

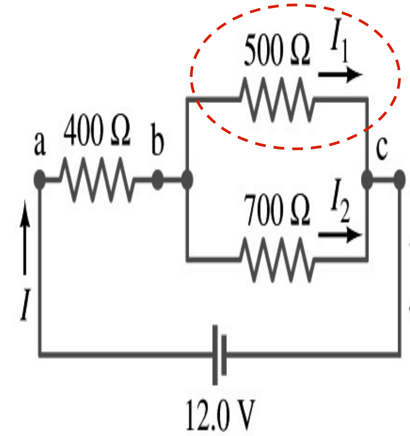
parallel $P_P = IV = \frac{V^2}{R_{eq}} = \frac{2V^2}{R} = 4P_S$

So parallel circuit provides brighter lighting.

(b) Car's headlights are in parallel to provide brighter lighting and also to prevent both lights going out at the same time when one burns out.

So what is bad about parallel circuits? Uses more energy in a given time.

Example 26 – 5



Current in one branch. What is the current flowing through the 500-Ω resister in the figure?

What do we need to find first?

We need to find the total current.

To do that we need to compute the equivalent resistance.

R_{eq} of the small parallel branch is: $$\frac{1}{R_P}=\frac{1}{500}+\frac{1}{700}=\frac{12}{3500} \qquad R_P=\frac{3500}{12}$$

R_{eq} of the circuit is: $$R_{eq}=400+\frac{3500}{12}=400+292=692\Omega$$

Thus the total current in the circuit is $$I=\frac{V}{R_{eq}}=\frac{12}{692}=17mA$$

The voltage drop across the parallel branch is $$V_{bc}=IR_P=17\times10^{-3}\cdot292=4.96V$$

The current flowing across 500-Ω resister is therefore

$$V_{bc}I_{500}=\frac{V_{bc}}{R}=\frac{4.96}{500}=9.92\times10^{-3}=9.92mA$$

What is the current flowing 700-Ω resister? $$I_{700}=I-I_{500}=17-9.92=7.08mA$$