PHYS 1441 – Section 002
Lecture #15

Monday, Oct. 26, 2020

Dr. Jaehoon Yu

- CH25
  - Microscopic View of Electric Current
  - Ohm's Law in Microscopic View
- CH26
  - EMF and Terminal Voltage
  - Resistors in Series and Parallel
  - Kirchhoff's Rules

Today's homework is homework #8, due 11pm, Friday, Nov. 6!!

Announcements

- Reminder for reading assignments: CH25 – 9, 25 – 10 and CH26 – 7
- We will have the mid-term grade discussion this **Wednesday, Oct. 28**, starting 11:30am ending at 4:30pm on a separate zoom link below
  - You **MUST** sign up on the doodle poll for the discussion https://doodle.com/poll/zpad5me89scp2whd
  - Each 30min slot is limited to 15 students
  - Only 37 of you have signed up for this discussion ➔ Without signing up to the time slot, you will not be able to have the discussion
  - Grade discussion zoom link: https://uta.zoom.us/j/98724294579?pwd=MlBJQXF3RnNZamtUbzQ3b3FXd2VIdz09
  - Will be counted attendance extra credit
- Those of you with additional COVID-19 questions can send email to Dr. Linda Lee at lindalee.17@gmail.com.
  - To ensure that she reads your email, please be sure to use subject: "Questions from Dr. Yu's student fall20"

SP#5 – Civic Duty II: Election Participation

- Election on **Nov. 3** with **early voting Tue. Oct. 13 – Fri. Oct. 30**
- For those with legal voting rights: You can submit three access code green sheet for 20 points total – one your own and two others who voted, 5 points each. Any additional ones will earn 2 points each
- For those without legal voting rights: You can submit for the first four access code green sheets for 20 points total, 5 points each and any additional combinations 2 points each.
- Be sure to tape one side of the access code (or "I Voted" sticker if the voting was not using an electronic machine) on a sheet of paper with the date, the precinct number, the name of the person voted
- None of the stickers can be from the same person on someone else's extra credit or on your own. All of those with any of the identical persons on your extra credit sheet will get 0 credit.
- Deadline: Beginning of the class **Monday, Nov. 9**

Access code sheet/Sticker

This must be accompanied with date of the vote, the county name, the precinct number, the full name of the person voted and the signature of the person

Reminder: Special Project #7 – Electric Power Usage

- Make a list of the power consumption and the resistance of all electric and electronic devices at your home and compile them in a table. (10 points total for the first 10 items and 0.5 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. (5 points total for the first 10 items and 0.2 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. (8 points)
- Due: Beginning of the class **Monday, Nov. 2**
  - Scan all pages of your special project into the pdf format
  - Save all pages into one file with the filename SP7-YourLastName-YourFirstName.pdf
  - Submit on CANVAS
  - Download the spreadsheet ASAP

Your Name						Electricity Rate					$/kWh	
Item Name	**Rated power (W)**	**Number of devices**	**Number of Hours per day**	**Daily Power Consumption (kWh)**	**Energy Cost per kWh (cents)**	**Daily Energy Consumption (J).**	**Daily Energy Cost ($)**	**Monthly Energy Consumption (J)**	**Monthly Energy Cost (S)**	**Yearly Energy Consumption (J)**	**Yearly Energy Cost ($)**	
Light Bulbs	30	4										
	40	6										
	60	15										
Heaters	1000	2										
	1500	1										
	2000	1										
Home Appliances (Fans, vacuum cleaners, hair dryers, pool pumps, etc)												
Air Conditioners												
Kitchen Appliances (Fridges, freeezers, cook tops, microwave ovens, toaster ovens, etc)												
Computing devices (desktop, laptop, ipad, mobile phones, printers, chargers, etc))												
Tools (power tools, electric mower, electric cutter, etc)												
Medical Devices (blood pressure machine, thermometer, etc)												
Transporations (electric cars, electric bicycles, electric motor cycles, etc												
Total												

Power Delivered by Alternating Current

- The square root of means of the squares of the current and voltage are called root-mean-square, or rms ➔ effective I & V

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

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

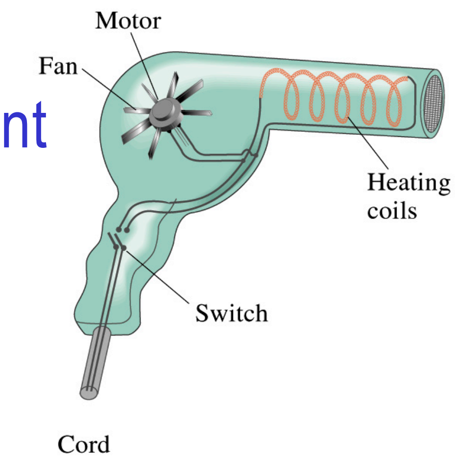
- AC Average Power using rms quantities

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

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

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

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 …

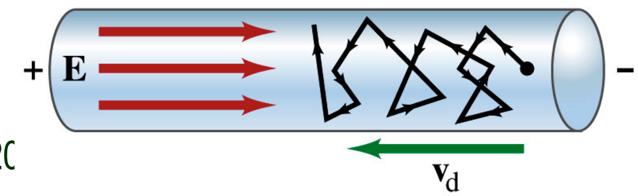
The average power provide by the AC in UK is

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

So? The heating coils in the dryer will melt!

Microscopic View of Electric Current

- When voltage is applied across the ends of a wire
- Electric field is generated by the potential difference
- Electrons feel the 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.

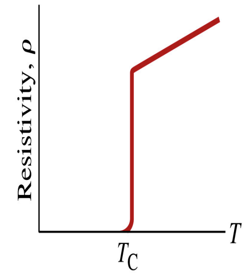


Microscopic View of Electric Current

- 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 the 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 close to the positive terminal flows into the bulb.
    - 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^{o}C).
    - 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 1986 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



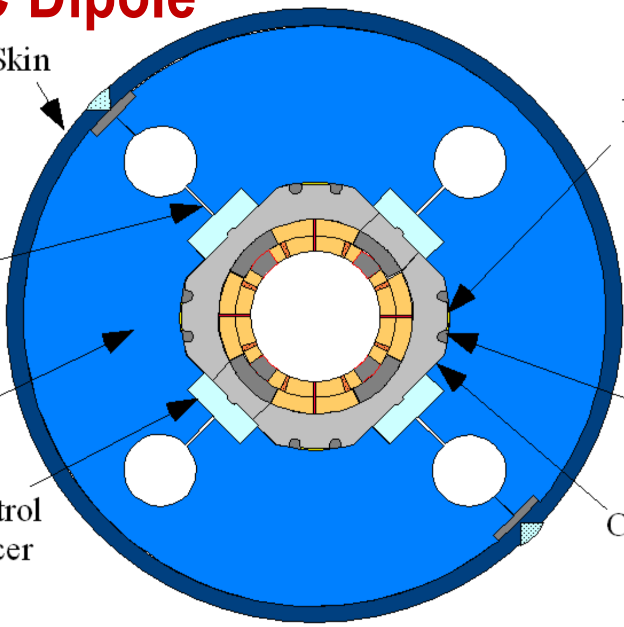
Critical Temperature of Superconductors

Selection of confirmed superconductors and common cooling agents

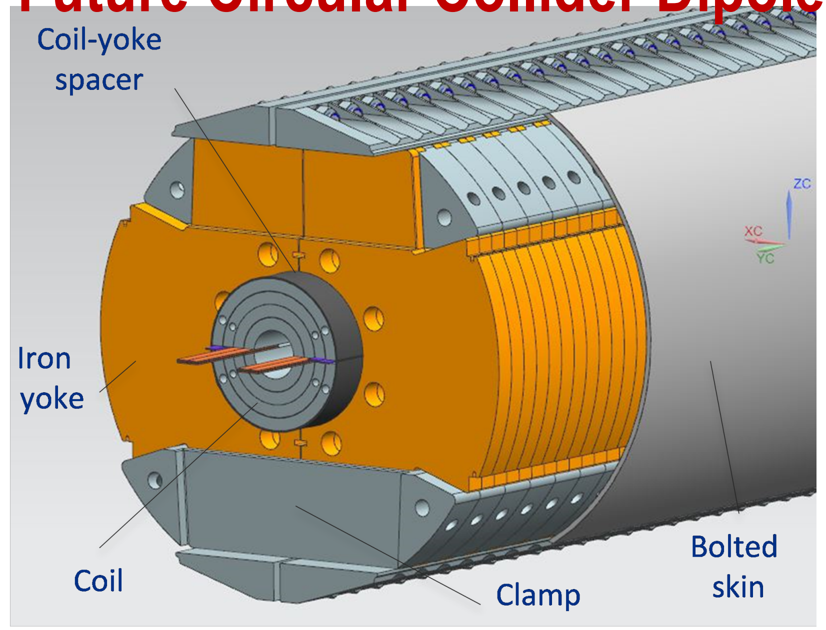
T_C respectively boiling point in K	T_C respectively boiling point in °C	Material	Notes
287	14	$H_2S + CH_4$ at 267 GPa @p=267GPa	First room temperature superconductor[21] Oct. 14, 2020
250	−23	LaH_{10} at 170 GPa	metallic superconductor with one of the highest known critical temperature
203	−70	High pressure phase of hydrogen sulfide at 100 GPa	mechanism unclear, observable isotope effect[22]
194.6	−78.5	Carbon dioxide: Sublimation point at atmospheric pressure (common cooling agent; for reference)	
138	−135	$Hg_{12}Tl_3Ba_{30}Ca_{30}Cu_{45}O_{127}$	high-temperature superconductors with copper oxide with relatively high critical temperatures
110	−163	$Bi_2Sr_2Ca_2Cu_3O_{10}$ (BSCCO)	
92	−181	$YBa_2Cu_3O_7$ (YBCO)	
87	−186	Argon: Boiling point at atmospheric pressure (common cooling agent; for reference)	
77	−196	Nitrogen: Boiling point at atmospheric pressure (common cooling agent; for reference)	
45	−228	$SmFeAsO_{0.85}F_{0.15}$	low-temperature superconductors with relatively high critical temperatures
41	−232	CeOFeAs	
39	−234	MgB_2	metallic superconductor with relatively high critical temperature at atmospheric pressure
30	−243	$La_{2-x}Ba_xCuO_4$[23]	First high-temperature superconductor with copper oxide, discovered by Bednorz and Müller
27	−246	Neon: Boiling point at atmospheric pressure (common cooling agent; for reference)	
21.15	−252	Hydrogen: Boiling point at atmospheric pressure (common cooling agent; for reference)	
18	−255	Nb_3Sn[23]	metallic low-temperature superconductors with technical relevance
9.2	−264.0	NbTi[24]	
4.21	−269.94	Helium: Boiling point at atmospheric pressure (common cooling agent of low temperature physics; for reference)	
4.15	−269.00	Hg (Mercury)[25]	metallic low-temperature superconductors
1.09	−272.06	Ga (Gallium)[25]	

Some Devices with Super-conductor

LHC Dipole



Future Circular Collider Dipole



LHC Dipole being installed

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".
  - Tissue is burn above 5A current
  - See http://www.elcosh.org/document/1624/888/d000543/section2.html
- A dry human body between two points on the opposite side of the body is about 10^4 to 10^6 Ω.
- But 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:

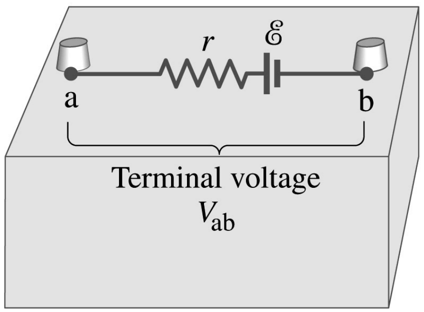
$$I = \frac{V}{R} = \frac{120V}{1000\Omega} = 120mA$$

  - Could be lethal

EMF and Terminal Voltage

- What do we need to have a 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".
- The potential difference between the 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), however, 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

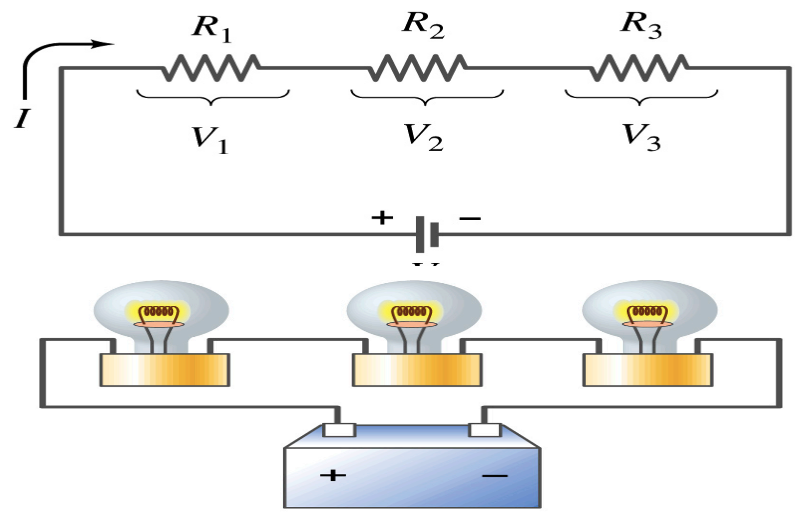
EMF and Terminal Voltage



- Since the internal resistance is inside the battery, we can never separate them out.
- 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 a voltage drop due to the internal resistance which is equal to Ir. Thus the actual **delivered** terminal voltage is $V_{ab} = \varepsilon - Ir$

Resistors in Series

- Resistors are in series when two or more resistors are **connected end to end**
  - These resistors represent simple resistors in a circuit of electric devices, such as light bulbs, heaters, dryers, etc



- What is common in a circuit connected in series?
  - **The 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, $R_{eq}=R_1+R_2+R_3$

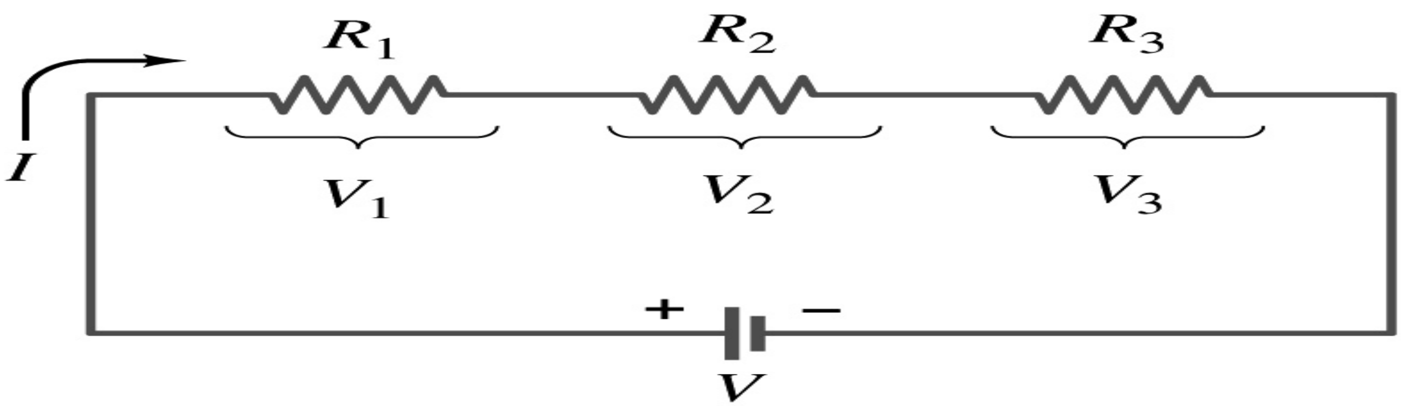
$$R_{eq} = \sum_i R_i$$

Resistors in series

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

Energy Losses in Resistors

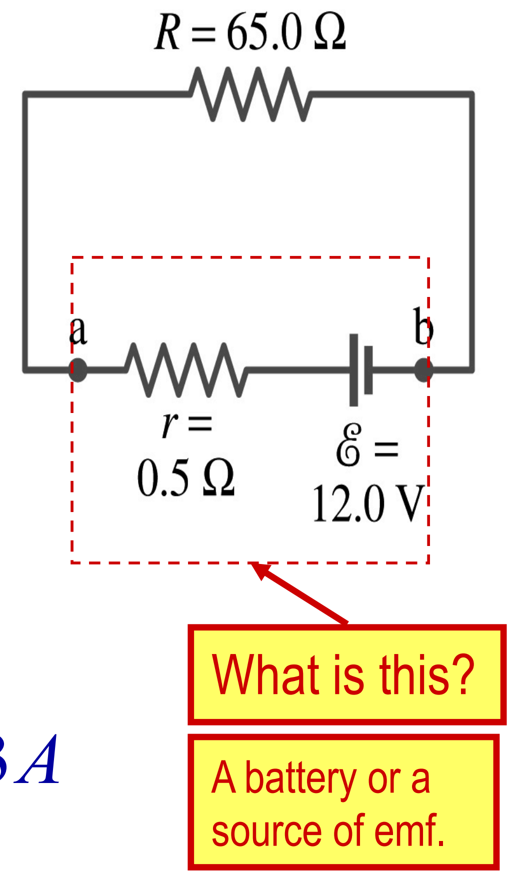
- Why is it true that $V=V_1+V_2+V_3$?



- What is the potential energy loss when charge q passes through resistors 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.



(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 $V_{ab} = \varepsilon - Ir = 12.0V - 0.183A \cdot 0.5\Omega = 11.9V$

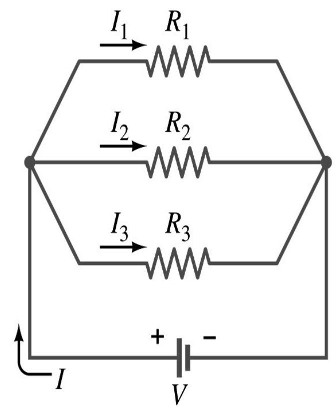
(c) The power dissipated in R and r are

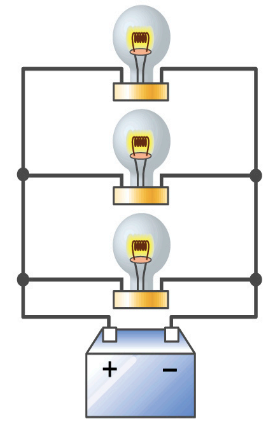
$$P = I^2 R = (0.183A)^2 \cdot 65.0\Omega = 2.18W$$

$$P = I^2 r = (0.183A)^2 \cdot 0.5\Omega = 0.02W$$

Resistors in Parallel

- Resistors are in parallel when two or more resistors 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 resistors.
  - The total current that leaves the battery, is however, split.
- The current that passes through each 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, $1/R_{eq}=1/R_1+1/R_2+1/R_3$

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

resistors in parallel

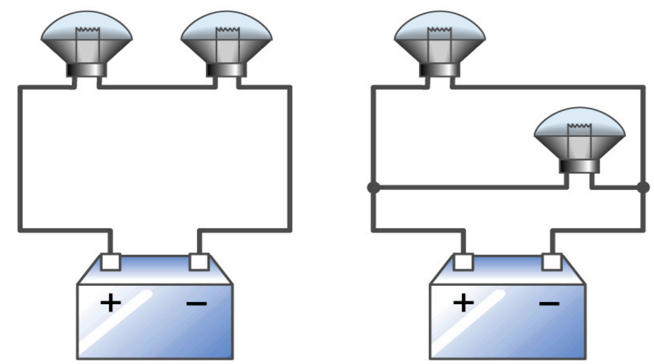
When resistors are connected in parallel, the total resistance decreases and the current increases.

Resistor and Capacitor Arrangements

- Parallel Capacitor arrangements $$C_{eq} = \sum_i C_i$$
- Parallel Resistor 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 Resistor 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.

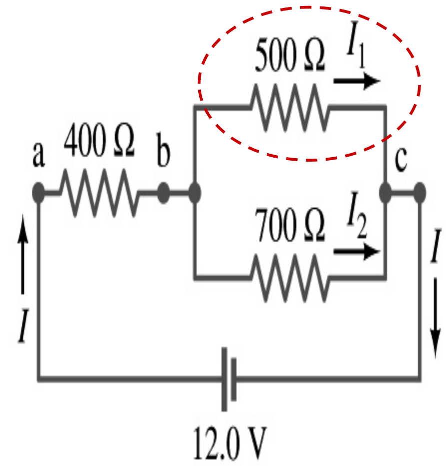
series $P_S = IV = \frac{V^2}{R_{eq}} = \frac{V^2}{2R}$ parallel $P_P = IV = \frac{V^2}{R_{eq}} = \frac{2V^2}{R} = 4P_S$

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 resistor 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 $$V_{bc} = IR_P = 17 \times 10^{-3} \cdot 292 = 4.96V$$

The current flowing across 500-Ω resistor is therefore

$$V_{bc} I_{500} = \frac{V_{bc}}{R} = \frac{4.96}{500} = 9.92 \times 10^{-3} = 9.92mA$$

What is the current flowing 700-Ω resistor?

$$I_{700} = I - I_{500} = 17 - 9.92 = 7.08mA$$