PHYS 1444 – Section 004
Lecture #13

Monday, Mar. 5, 2012
Dr. Jaehoon Yu

- Kirchhoff's Rules
- EMFs in Series and Parallel
- RC Circuits
  - Analysis of RC Circuits
  - Discharging of RC Circuits
  - Application of RC Circuits
- Magnetism and Magnetic Field

Today's homework is #8, due 10pm, Friday, Mar. 16!!

Announcements

- Term exam results
  - Class average: 56.7/98
    - Equivalent to: 57.1/100
  - Top core: 88/98
  - This could be replaced by the 2nd non-comprehensive term exam on Apr. 25.
- Mid-term comprehensive exam
  - Wednesday, Mar. 21
  - Time and place: 5:30 – 6:50pm, SH103
  - Comprehensive exam
  - Covers: CH21.1 through what we finish on Wednesday, Mar. 7 plus Appendices A and B
  - Please do NOT miss the exam! You will get an F!!
- Reading assignment: CH26.7
- Colloquium this week
  - Dr. Zhenhai Xia of UNT

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Biomimetic Design of Carbon Nanomaterials for Dry Adhesives

Dr. Zhenhai Xia

Department of Materials Science and Engineering
University of North Texas

4:00 pm Wednesday March 7, 2012 room 101 SH

Abstract:

Geckos can climb on almost any vertical surface, whether hydrophilic or hydrophobic, rough or smooth. The extraordinary ability of geckos is attributed to their fine hairy structure of their toes, which allow for intimate contacts between the nanohairs and almost any surface to secure high adhesion forces to defray gravity through van der Waals forces. Mimicking this biological system can lead to the development of a new class of advanced adhesives useful in various applications, including climbing robots, reusable tapes, super-grip tires, high efficiency breaks and rapid patch repairs on military vehicles. In this talk, I will present our recent efforts on the development of artificial dry adhesives. Using carbon nanotube arrays that are dominated by a straight body-segment but with curly entangled tip, we have created gecko-foot-mimetic dry adhesives that show macroscopic adhesive forces of ~100 N/cm^2, almost ten times of that of a gecko foot. The mimics can be alternatively strong binding-on and easy lifting-off over various substrates for simulating the walking of a living gecko. To understand the underling mechanisms, a multiscale modeling approach was developed by combining large-scale finite element analysis, mesoscale coarse-grained modeling and fully atomic molecular dynamics simulation. Adhesion and friction behaviors of the nanotube arrays under various loading conditions are characterized and compared with experimental data. Good agreements are obtained, which give an insight into the anisotropic adhesive behaviors of carbon nanotubes on rough substrates.

Refreshments will be served at 3:30p.m in the Physics Library

Reminder: Special Project #3

- Make a list of the ***rated power*** and the ***resistance*** of all electric and electronic devices at your home and compiled them in a table. (0.5 points each for the first 10 items and 0.1 points 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 (taking into account the number of hours you use the device) on the table using the electricity cost per kWh of the power company that serves you and put them in a separate column in the above table for each of the items. (0.2 points each for the first 10 items and 0.1 points each additional items). Clearly write down what the unit cost of the power is per kWh above the table.
- 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 Wednesday, Mar. 7

Special Project Spread Sheet

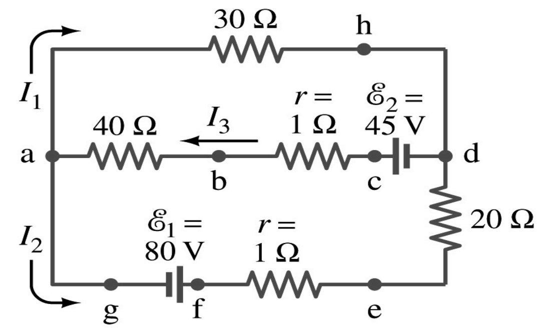
PHYS1444-003, Fall11, Special Project #4

Download this spread sheet from: http://www-hep.uta.edu/~yu/teaching/spring12-1444-004/sp3-spreadsheet.xlsx

Item Names	Rated power (W)	Number of devices	usage: Number of Hours per day	Daily			Monthly			Yearly		
				Power Consumption (kWh)	Energy Usage (J)	Energy cost ($)	Power Consumption (kWh)	Energy Usage (J)	Energy cost ($)	Power Consumption (kWh)	Energy Usage (J)	Energy cost ($)
Light Bulbs	30, 40, 60, 100, etc	40										
Heaters												
Fans												
Air Conditioner												
Fridgers, Freezers												
Computers												
Game consoles												
Total				0	0	0	0					

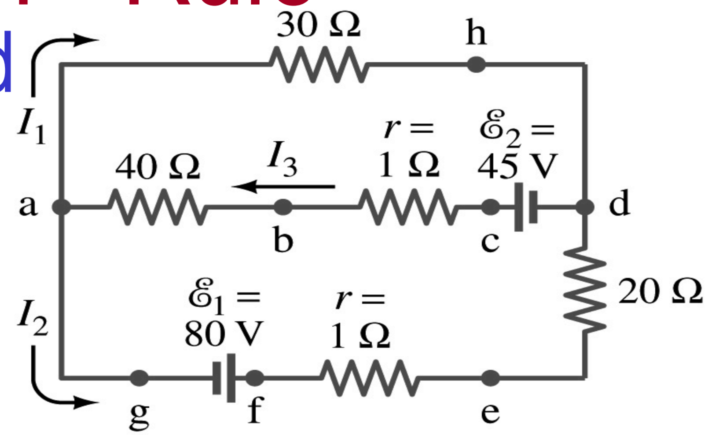
Special Project #4

- In the circuit on the right, find out what the currents I_1, I_2 and I_3 are using Kirchhoff's rules in the following two cases:



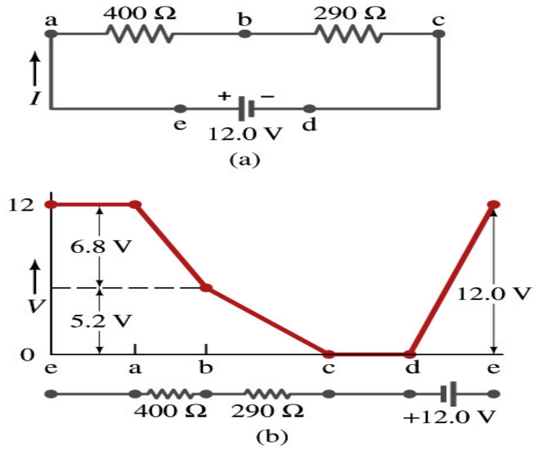
  - All the directions of the current flows are as shown in the figure. (3points)
  - When the directions of the flow of the current I_1 and I_3 are opposite than drawn in the figure but the direction of I_2 is the same. (5 points)
  - When the directions of the flow of the current I_2 and I_3 are opposite than drawn in the figure but the direction of I_1 is the same. (5 points)
- Show the details of your OWN work to obtain credit.
- Due is at the beginning of the class Monday, Mar. 26.

Kirchhoff's Rules – 1st Rule



- Some circuits are very complicated to analyze using the simple combinations of resisters
  - G. R. Kirchhoff devised two rules to deal with complicated circuits.
- Kirchhoff's rules are based on **conservation of charge and energy**
  - Kirchhoff's 1st rule: The junction rule, charge conservation.
    - At any junction point, the sum of all currents entering the junction must be equal to the sum of all currents leaving the junction.
    - In other words, what goes in must come out.
    - At junction *a* in the figure, I_3 comes into the junction while I_1 and I_2 leaves: $I_3 = I_1 + I_2$

Kirchhoff's Rules – 2nd Rule

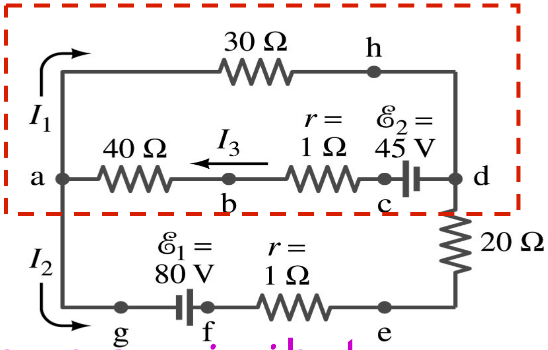


- Kirchoff's 2nd rule: The loop rule, uses conservation of energy.
  - The sum of the changes in potential around any closed path of a circuit must be zero.
- The current in the circuit in the figure is I=12/690=0.017A.
  - Point e is the high potential point while point d is the lowest potential.
  - When the test charge starts at e and returns to e, the total potential change is 0.
  - Between point e and a, no potential change since there is no source of potential nor any resister.
  - Between a and b, there is a 400Ω resister, causing IR=0.017*400 =6.8V drop.
  - Between b and c, there is a 290Ω resister, causing IR=0.017*290 =5.2V drop.
  - Since these are voltage drops, we use negative sign for these, -6.8V and -5.2V.
  - No change between c and d while from d to e there is +12V change.
  - Thus the total change of the voltage through the loop is: -6.8V-5.2V+12V=0V.

Using Kirchhoff's Rules

1. Determine the flow of currents at circuit junctions and label each and everyone of the currents.
   - It does not matter which direction, you decide.
   - If the value of the current after completing the calculations are negative, you just need to flip the direction of the current flow.
2. Write down the current equation based on Kirchhoff's 1st rule at various junctions.
   - Be sure to see if any of them are the same.
3. Choose closed loops in the circuit
4. Write down the potential in each interval of the junctions, keeping the signs properly.
5. Write down the potential equations for each loop.
6. Solve the equations for unknowns.

Example 26 – 9



Use Kirchhoff's rules. Calculate the currents I_1, I_2 and I_3 in each of the branches of the circuit in the figure.

The directions of the current through the circuit is not known a *priori* but since the current tends to move away from the positive terminal of a battery, we arbitrarily choose the direction of the currents as shown.

We have three unknowns so we need three equations.

Using Kirchhoff's junction rule at point *a*, we obtain $$I_3 = I_1 + I_2$$

This is the same for junction *d* as well, so no additional information.

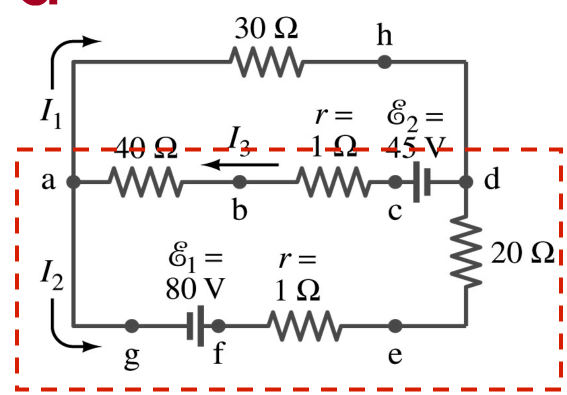
Now the second rule on the loop *ahdcba*.

$$V_{ah} = -I_1 30 \qquad V_{hd} = 0 \qquad V_{dc} = +45 \qquad V_{cb} = -I_3 \qquad V_{ba} = -40I_3$$

The total voltage change in the loop *ahdcba* is.

$$V_{ahdcba} = -30I_1 + 45 - 1 \cdot I_3 - 40I_3 = 45 - 30I_1 - 41I_3 = 0$$

Example 26 – 9, cnt'd



Now the second rule on the other loop *agfedcba*.

$V_{ag} = 0 \quad V_{gf} = +80 \quad V_{fe} = -I_2 \cdot 1 \quad V_{ed} = -I_2 \cdot 20$

$V_{dc} = +45 \quad V_{cb} = -I_3 \cdot 1 \quad V_{ba} = -40 \cdot I_3$

The total voltage change in loop *agfedcba* is. $V_{agf\,edcba} = -21I_2 + 125 - 41I_3 = 0$

So the three equations become

$$I_3 = I_1 + I_2$$

$$45 - 30I_1 - 41I_3 = 0$$

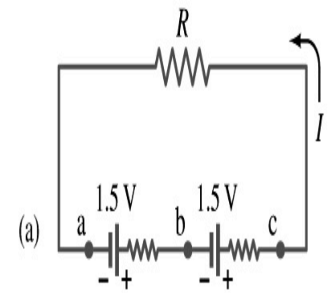
$$125 - 21I_2 - 41I_3 = 0$$

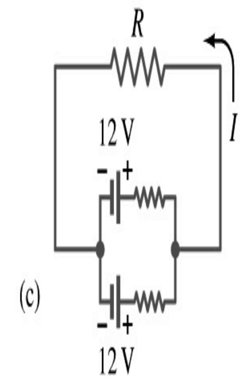
We can obtain the three current by solving these equations for I_1, I_2 and I_3.

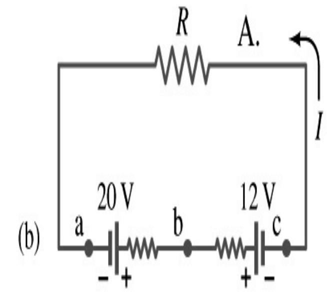
Do this yourselves!!

EMFs in Series and Parallel: Charging a Battery

- When two or more sources of emfs, such as batteries, are connected in series
  - The total voltage is the algebraic sum of their voltages, if their direction is the same
    - V_{ab}=1.5 + 1.5=3.0V in figure (a).
  - If the batteries are arranged in an opposite direction, the total voltage is the difference between them



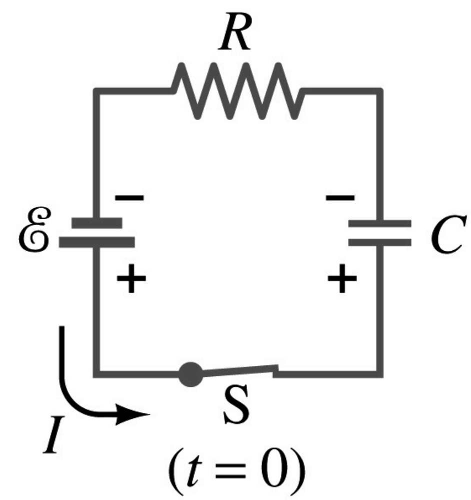




Parallel arrangements (c) are used only to increase currents. An example?

    - V_{ac}=20 – 12=8.0V in figure (b)
    - Connecting batteries in opposite direction is wasteful.
    - This, however, is the way a battery charger works.
    - Since the 20V battery is at a higher voltage, it forces charges into 12V battery
    - Some battery are rechargeable since their chemical reactions are reversible but most the batteries do not reverse their chemical reactions

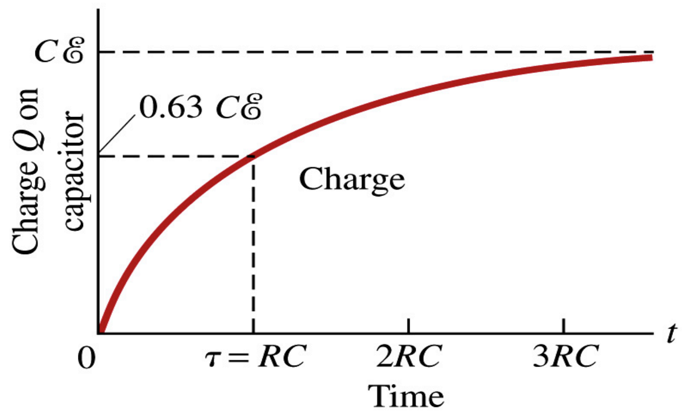
RC Circuits

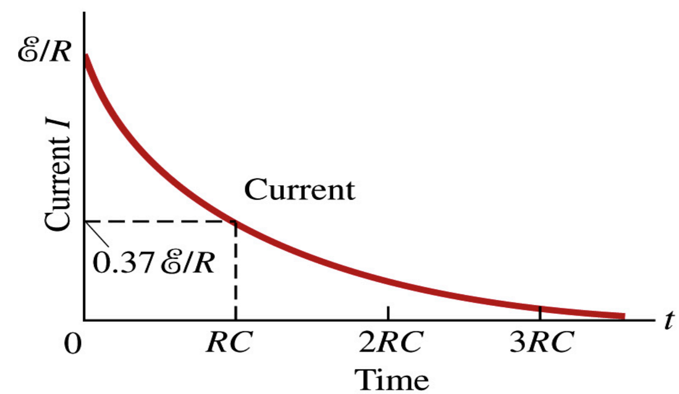


- Circuits containing both resisters and capacitors
  - RC circuits are used commonly in everyday life
    - Control windshield wiper
    - Timing of traffic light from red to green
    - Camera flashes and heart pacemakers
- How does an RC circuit look?
  - There should be a source of emf, capacitors and resisters
- What happens when the switch S is closed?
  - Current immediately starts flowing through the circuit.
  - Electrons flow out of negative terminal of the emf source, through the resister R and accumulates on the upper plate of the capacitor.
  - The electrons from the bottom plate of the capacitor will flow into the positive terminal of the battery, leaving only positive charges on the bottom plate.
  - As the charge accumulates on the capacitor, the potential difference across it increases
  - The current reduces gradually to 0 till the voltage across the capacitor is the same as emf.
  - The charge on the capacitor increases till it reaches to its maximum $C\mathscr{E}$.

RC Circuits

- How does all this look like in graphs?
  - The charge and the current on the capacitor as a function of time





  - From energy conservation (Kirchhoff's 2nd rule), the emf $\mathscr{E}$ must be equal to the voltage drop across the capacitor and the resister
    - $\mathscr{E} = IR + Q/C$
    - R includes all resistance in the circuit, including the internal resistance of the battery, I is the current in the circuit at any instance, and Q is the charge of the capacitor at that same instance.

Analysis of RC Circuits

- From the energy conservation, we obtain $\mathscr{E}=I\mathscr{R}+Q/C$
- Which ones are constants in the above equation?
  - $\mathscr{E}$, $\mathscr{R}$ and C are constant
  - Q and I are functions of time
- How do we write the rate at which the charge is accumulated on the capacitor?
  - We can rewrite the above equation as $\varepsilon = R\frac{dQ}{dt}+\frac{1}{C}Q$
  - This equation can be solved by rearranging the terms as $\frac{dQ}{C\varepsilon - Q}=\frac{dt}{RC}$

Analysis of RC Circuits

- Now integrating from $t=0$ when there was no charge on the capacitor to t when the capacitor is fully charged, we obtain
- $\int_0^Q \frac{dQ}{C\varepsilon - Q} = \frac{1}{RC}\int_0^t dt$ ➔
- $-\ln\left(C\varepsilon - Q\right)\Big|_0^Q = -\ln\left(C\varepsilon - Q\right) - \left(-\ln C\varepsilon\right) = \frac{t}{RC}\Big|_0^t = \frac{t}{RC}$
- So, we obtain $\ln\left(1 - \frac{Q}{C\varepsilon}\right) = -\frac{t}{RC}$ ➔ $1 - \frac{Q}{C\varepsilon} = e^{-t/RC}$
- Or $Q = C\varepsilon\left(1 - e^{-t/RC}\right)$
- The potential difference across the capacitor is V=Q/C, so $V_C = \varepsilon\left(1 - e^{-t/RC}\right)$

Analysis of RC Circuits

- Since $Q = C\varepsilon\left(1 - e^{-t/RC}\right)$ and $V_C = \varepsilon\left(1 - e^{-t/RC}\right)$
- What can we see from the above equations?
  - Q and V_C increase from 0 at t=0 to maximum value Q_{max}=C$\mathcal{E}$ and V_C= $\mathcal{E}$.
- In how much time?
  - The quantity RC is called the time constant of the circuit, τ
    - τ=RC, What is the unit? Sec.
  - What is the physical meaning?
    - The time required for the capacitor to reach $(1-e^{-1})=0.63$ or 63% of the full charge
- The current is $I = \frac{dQ}{dt} = \frac{\varepsilon}{R} e^{-t/RC}$