MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Physics

8.02 **Fall 2007**

Turn in to boxes at classroom entrance labeled with your name and group (e.g. L02 2A)

Problem Set 6

Due: Wednesday, October 17th at beginning of class (before 10:15/1:15)

<u>Warm Up</u>

Problem 1: Short Questions

(a) If charges flow very slowly through a metal, why does it not require several hours for light to come on when you throw a switch?

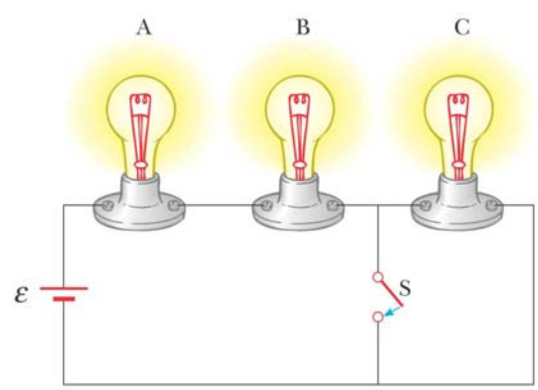
(b) What advantage does 120-V operation offer over 240 V? What are the disadvantages?

(c) Why is it possible for a bird to stand on a high-voltage wire without getting electrocuted?

(d) If your car's headlights are on when you start the ignition, why do they dim while the car is starting?

(e) Suppose a person falling from a building on the way down grabs a high-voltage wire. If the wire supports him as he hangs from it, will he be electrocuted? If the wire then breaks, should he continue to hold onto the end of the wire as he falls?

(f) A series circuit consists of three identical lamps connected to a battery as shown in the figure below. When the switch S is closed, what happens to the brightness of the light bulbs? Explain your answer.



Analytic Problems…

Problem 2: Battery Life

AAA, AA, … D batteries have an open circuit voltage (EMF) of 1.5 V. The difference between different sizes is in their lifetime (total energy storage). A AAA battery has a life of about 0.5 A-hr while a D battery has a life of about 10 A-hr. Of course these numbers depend on how quickly you discharge them and on the manufacturer, but these numbers are roughly correct. One important difference between batteries is their internal resistance – alkaline (now the standard) D cells are about 0.1Ω.

Suppose that you have a multi-speed winch that is 50% efficient (50% of energy used does useful work) run off a D cell, and that you are trying to lift a mass of 60 kg (hmmm, I wonder what mass that would be). The winch acts as load with a variable resistance R_L that is speed dependent.

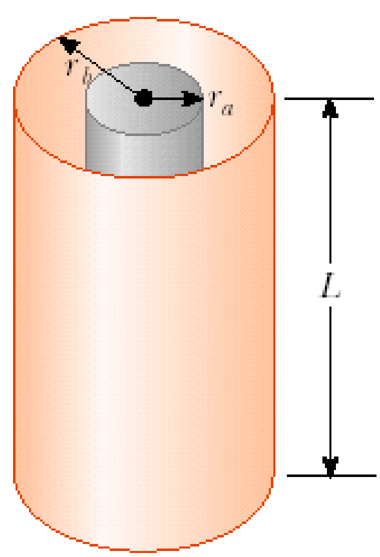
a) Suppose the winch is set to super-slow speed. Then the load (winch motor) resistance is much greater than the battery's internal resistance and you can assume that there is no loss of energy to internal resistance. How high can the winch lift the mass before discharging the battery?

b) To what resistance R_L should the winch be set in order to have the battery lift the mass at the fastest rate? What is this fastest rate (m/sec)? HINT: You want to maximize the power delivery to the winch (power dissipated by R_L).

c) At this fastest lift rate how high can the winch lift the mass before discharging the battery?

Problem 3: Sea Water

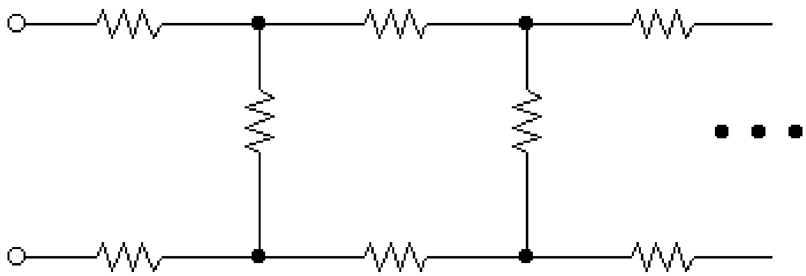
An oceanographer is studying how the ion concentration in sea water depends on depth. She does this by lowering into the water (until completely submerged) a pair of concentric metallic cylinders (see figure) at the end of a cable and taking data to determine the resistance between these electrodes as a function of depth. The water between the two cylinders forms a cylindrical shell of inner radius r_a, outer radius r_b, and length L much larger than r_b. The scientist applies a potential difference ΔV between the inner and outer surfaces, producing an outward radial current I. Let ρ represent the resistivity of the water.



Find the resistance of the water between the cylinders in terms of L, ρ, r_a, and r_b.

Problem 4: Resistor Ladder

Consider the infinite ladder of resistors below formed by using identical 1 Ω resistors.



What is the resistance that you will measure between the two nodes at left? HINT: This is conceptually similar to calculating the value of repeating fractions, e.g.

$$f = 1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{\cdots}}}$$

It pays to remember that ∞-1≅∞.

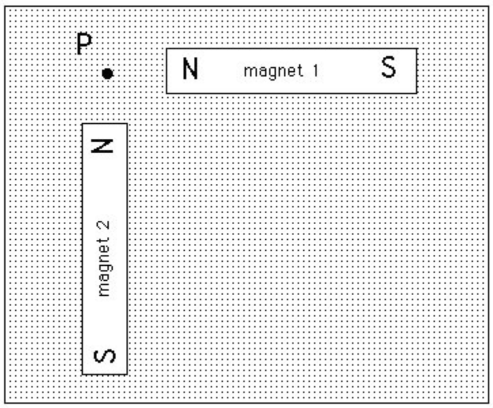
<u>Approximations, Fermi Problems, Back of the Envelope Calculations…</u>

Problem 5: Energy Cost

Compare the cost of powering a desk light with D cells as opposed to plugging it into the wall. Does it make sense to use rechargeable batteries? HINT: You can find some useful numbers in problem 2.

<u>Experiment 3: Magnetic Fields Pre-Lab Questions</u>

Problem 6: Superposition



Consider two bar magnets placed at right angles to each other, as pictured at left.

(a) If a small compass is placed at point P, what direction does the painted end of the compass needle point?

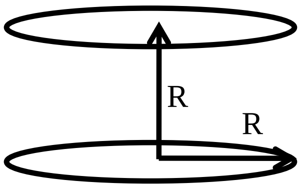
(b) If the compass needle instead pointed 15 degrees clockwise of where you predicted in (a), what could you *qualitatively* conclude about the relative strengths of the two magnets?

Problem 7: Helmholtz Coil

In class you calculated the magnetic field along the axis of a coil to be given by:

$$B_{axial} = \frac{N\,\mu_0\,I\,R^2}{2}\frac{1}{(z^2+R^2)^{3/2}}$$

where z is measured from the center of the coil.



As pictured at left, a Helmholtz coil is created by placing two such coils (each of radius *R* and *N* turns) a distance *R* apart.

(a) If the current in the two coils is parallel (Helmholtz configuration), what is the axial field strength at the center of the apparatus (midway between the two coils)? How does this compare to the field strength at the center of the single coil configuration (e.g. what is the ratio)?

(b) In the anti-Helmholtz configuration the current in the two coils is anti-parallel. What is field strength at the center of the apparatus in this situation?

(c) Our coils have a radius *R* = 7 cm and *N* = 168 turns, and we will run with *I* = 0.6 A in single coil and 0.3 A in Helmholtz and anti-Helmholtz mode. What, approximately, are the largest on-axis fields we should expect in these three configurations? Where (***approximately*** – for the anti-Helmholtz don't calculate exactly, only approximate) are the fields the strongest? ***Write the answer to this question in your notes. You will need it for the lab.***