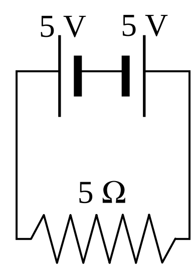
Physics 122, sections 502-4 and 8101
Laura Lising

Assignment 4
Due March 4, start of class

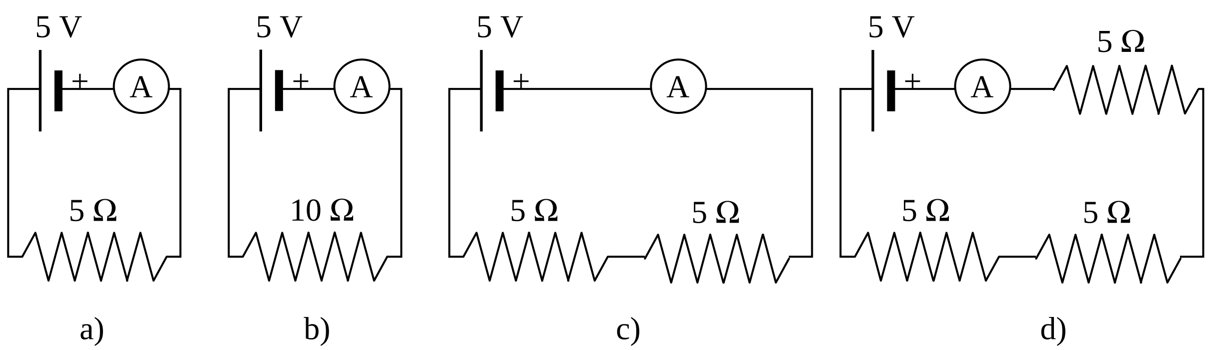
Reference: Cutnell & Johnson is Chapter 20, sections 10 and 11; the topics are Kirchoff's Rules, current and voltage.

You <u>must</u> explain your reasoning! You can do that using mathematics or words or diagrams, but I'm asking the TAs to give <u>no credit for answers without explanation</u>, even if the answer is correct.

1) Suppose that you have a circuit with two batteries and one resistor, with the batteries oriented oppositely as shown.
   a) Using Kirchoff's loop rules, find the current through the resistor.
   b) Now think about your understanding of circuits using the analogies from class. (Hopefully you were already doing this – always check your calculations with your common sense!) Explain how your answer for part a does or doesn't fit with what the analogies would tell you.

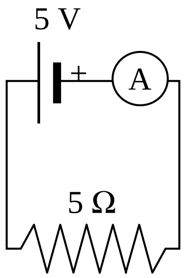


2) a-d) For the four circuits below, use Kirchoff's rule to figure out the current through the ammeter.

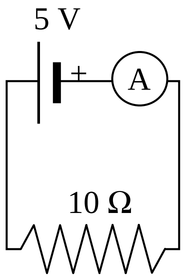


e) Do you see a trend in circuits a), c), and d) for how the current depends on how many resistors you add? Use this trend to predict the current in a circuit like d) that had five resistors (all 5 Ω) in a row instead of three.
f) In what way are circuits b) and c) alike? What one resistor would need to replace the resistor in b) to make b) similar to circuit d)?
g) Can you make sense of what you figured out in e) and f) with the analogies? Explain why the analogies would or wouldn't tell you about the trend for adding resistors. Explain why the analogies would or wouldn't tell you about how resistors in a row (we call these "in series") are similar to a single bigger resistor. To help you (and the TAs when grading), draw a picture of circuits b) and c) using one (or both) of the analogies.

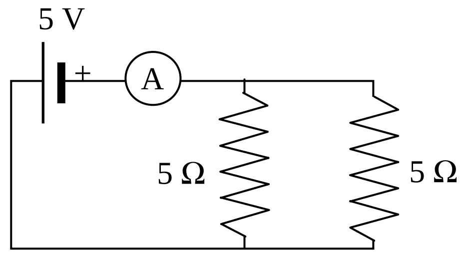
3) a-e) For the five circuits below, use Kirchoff's rule to figure out the current through the ammeter.



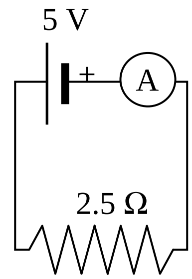
a)



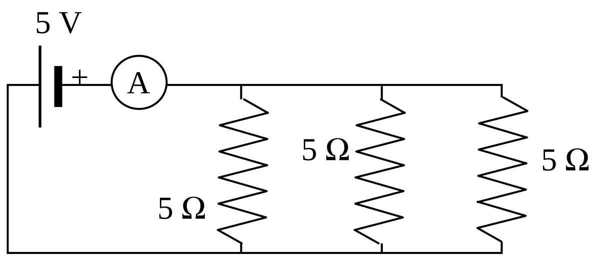
b)



c)



d)



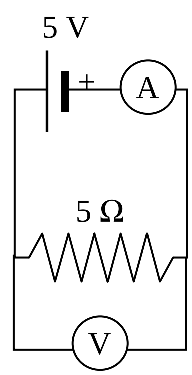
e)

f) Do you see a trend in circuits a), c), and e) for how the current depends on how many resistors you add? Use this trend to predict the current in a circuit like d) that had five resistors (all 5 Ω) instead of three, hooked up not in a row like in problem 2), but with a new loop for each one like in c) and e). (We call these resistors "in parallel.")

g) Is circuit c) more like b) or d)? What one resistor would need to replace the resistor in b) to make b) similar to circuit e)?

h) Can you make sense of what you figured out in f) and g) with the analogies? Explain why the analogies would or wouldn't tell you about the trend for adding resistors. Explain why the analogies would or wouldn't tell you about how resistors parallel are similar to a single smaller resistor. Draw a picture of circuits c) and d) using one (or both) of the analogies.

4) In class and in lab we've used voltmeters and ammeters. We said that the way the ammeter works was that it had to be hooked in line in the circuit, so the current passed through it. Then it would count the charge passing by in a given time and give a reading. The voltmeter, on the other hand, connected not in line but in two places so it could compare the pressure (voltage) at those two places and give a reading of the difference. The circuit diagram with both a voltmeter and an ammeter looks like this.



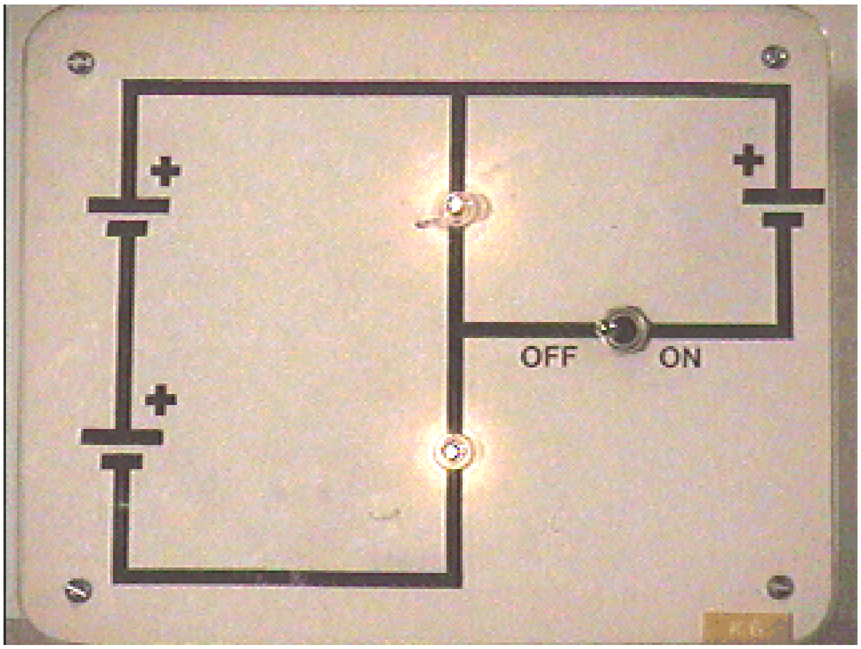
a) To work well, would you expect an ammeter to act as a conductor (almost no resistance), an insulator (very high resistance), or a resistor (in between)?

b) Same question, but for a voltmeter.

c) Suppose we made a mistake, and switched the meters – connected the voltmeter where the ammeter should be and vice versa. What would the meters read?

5) Here's a circuit puzzle I'm going to show you in lecture. (Would have made a great quiz! But I've gotten a little thrown off-schedule, quiz-wise, so you get it for homework.)

If I turn the switch on, it will make the connection and act as a wire. (That's what switches do!) The question: What will happen to the brightness of each of the two bulbs when I throw the switch? (Advice: Think about it in more ways than one – e.g. use Kirchoff's rules and an analogy – and then try to reconcile any discrepancy you find, between the different ways of thinking. As always!)



6) The inner and outer surfaces of a cell membrane carry a negative and positive charge respectively. Because of these charges, a potential difference of about 70 mV exists across the membrane. The thickness of the membrane is 8 nm. Cells can carry ions across a membrane *against the field* ("uphill") using a variety of active transport mechanisms. One mechanism does so by using up some of the cell's stored energy converting ATP to ADP. Suppose that it takes approximately 10^{-20} Joules to carry one sodium ion (missing one electron) across the membrane against the field.

a) What is the field inside the membrane? (Hint: First try to figure out the force on the ion inside the membrane. Then you'll need to use what you figured out at the end of this week's tutorial.)

b) How much energy is needed per mole of sodium to cross the membrane? Express this in Joules and KCal.

7) You were asked in class to explain why the electrical cords in your house, if they are drawing up to 10 Amps, didn't attract little bits of paper like the tapes we played with or

other charged objects we've studied. Also, when I asked, most students said that the wire connecting the two plates in problem 6 of assignment 2 would pick attract bits of paper until the plates got equal charges.

Most of the arguments I heard about the wires at home were from two camps, both having to do with the insulation.

Argument I: The insulation shields the force. The paper bits won't feel the force through the insulation.

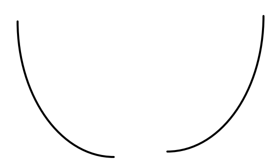
Argument II: The insulation doesn't shield the force, but it does keep the bits from getting close enough to the wire to feel a strong enough force to be attracted.

I also heard a few responses to these arguments. One response, from a student's observations, was to both arguments,

Response to I and II: Neither of these can explain why wires don't pick up paper bits, because I've seen circuits with wires that were not insulated, and they didn't attract paper bits.

Let me give you a little bit more to work on in figuring this out.

a) Estimate the charge on the pieces of tape. To do this, think about the two tapes attracting each other. The force between the two, even when they are not touching, is about equal to the gravitational force.



b) Now that you know the minimum charge you need to pick up paper bits, how does that knowledge help you to argue for or against arguments I or II?

c) Think about the model we have for charge. It seems to me that argument I is using concepts not in the model, namely shielding, an idea that we addressed in an earlier problem set. What can the model say about shielding effects? Argument II seems to be drawing directly from the model (noting that forces get weaker as the distance gets greater.) However, it rests on assumptions about the magnitude of the force at a certain distance (the thickness of the insulation.) Do our numbers for a) help us examine this assumption?

c) Think about our analogies for electricity. What's the analogy for a wire in each case? What's the analogy for charge? What's the difference between a wire with no current and a wire with current? Specifically, is there something in the wire when there is no current? If so, why isn't it moving?

8) (This question won't be graded, but it's an extra problem to work on before the midterm.) Suppose that you want to build a small heater out of a coil of wire made of the Nickel-Chromium alloy Nichrome (a resistive substance) and a 6 Volt battery in order to heat 30 ml of water from a temperature of 20 C to 40 C in 1 minute.
a) How much heat energy (in Joules) do you need to do this?

b) How much power (in Watts) do you need to do it in the time indicated?
c) What resistance should your Nichrome coil have in order to produce this much power in heat?
d) The resistance of a wire made of a resistive substance is given by the formula $R=\rho l/A$, where ρ is the resistivity or the substance (and internal property like density), l is the length of the wire, and A is the cross-sectional area. The Nickel-Chromium alloy Nichrome has a resistivity of about 10^{-6} Ω-m. Can you create a coil having the resistance you calculated you'd need? (Hint: Can you find a plausible length and cross sectional area for your wire that will give you the resistance you need?)