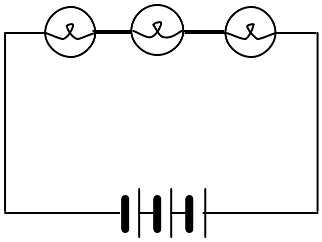
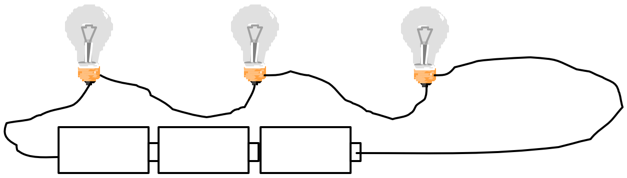
Physics 122, sections 502-4 and 8101 **Assignment 3 Solutions**
Laura Lising **Due Feb 25, start of class**

Reference: The closest reference in Cutnell & Johnson is Chapter 20, sections 1,2, 6, 7, and 8. Or look at the alternative reading linked on the course web page. The topics are current, resistance, voltage, Ohm's Law, and parallel and series circuits.

1) Here's a circuit for you to consider, and I'm going to ask you to try to think about it in several ways. Each of the batteries is a 1.5 V battery, and the bulbs are all identical. (These both depict the same circuit.

The overall question here is this: Which bulb, if any, would be the brightest? But I want you to answer it from three different ways of thinking about electricity.





a) Sometimes people think the reason there are two connections to the batteries is because a positive current flows out of one end and a negative current flows out of the other. It's when they hit each other that you get light. (Ampere had an idea just like that, in the early 1800s, known as Ampere's model of clashing currents.) How would someone thinking in this way answer the question?

People thinking in terms of clashing currents have a lot of trouble figuring out what should happen in this circuit! One line of reasoning goes like this: The middle bulb should be the brightest, because that's where the two kinds of current hit and mix in the best proportion. The other two might light a little if there's some extra flow from the two kinds of charge spilling over. Finding out that all the bulbs are equally bright is one bit of evidence for us that this "clashing currents" idea doesn't work: How would it happen that the two currents mix identically in all the bulbs?

b) In lecture we talked about an analogy to pulling a rope: Charge is like rope, moving charge is like moving rope, a battery is like someone pulling the rope to try to make it move, and a bulb is like something the rope rubs as it passes. How would someone using that analogy answer the question?

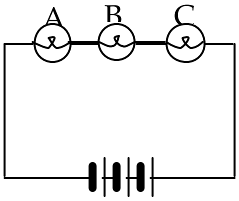
Since the same amount of rope has to go by, the amount of rubbing ought to be the same. (We talked about just this in lecture.)

c) We also talked about an analogy to flowing air: Charge is like air, moving charge is like moving air, a battery is like an air pump with a high pressure output and low pressure input, and a bulb is like a whistle that constricts the flow of air a little. How would someone using that analogy answer the question?

I find it easier to think about the rope, because it's so clear that it all has to move at once. With air, at least when you first turn the pump on, I'd think the first pinwheel would be the faster (or the flow through the first narrow straw), because it would have the most pressure on it from the pump. But… as the air flowed, if the air was flowing at a lower rate through the second pinwheel/straw than the first (less air per second), then the pressure would start going up in that connection – more air flowing in that flowing out. That couldn't last… in the long run, the pressures would have to adjust so that there'd be the same rate of air flowing through each straw/pinwheel, and they'd end up the same.

> Really, any way you have of picturing the amount of *stuff* (rope, air, water, dominoes, trains,cars, people in the department store) moving in the circuit—you don't lose any along the way-will eventually lead you to the idea that the rate of flow through any of the bulbs in series has to be the same. If it weren't, the stuff would have to be accumulating or leaking along the way. That's the key, it doesn't have to be smart stuff, it just has to not accumulate or leak.

2) This time, give what you think is the best answer, using whatever way or ways of thinking about it you choose. We'll start with the same circuit as in question 1, with three 1.5 V batteries, everything in series.



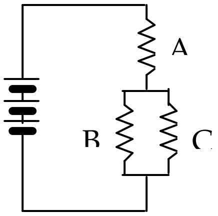
a) What's the voltage across each of the bulbs in this circuit? (i.e. the voltage from one side of the bulb to the other.)

Really, you already know part b – it would have been better to put that first! If the voltage drop from one side of each battery to the other is 1.5 V, then from the first battery to the last is 4.5 V. So the voltage across all three bulbs—from one side to the other—should be 4.5 V. Since the bulbs are all identical, and all have the same current, the voltage across each bulb should be 1.5 V.

b) How would the currents through each of those bulbs compare?

The current has to be the same through each bulb – that's what we were just doing in problem 1! We also know that the amount of current depends on the difference in electrical pressure from one side of the bulb to the other, and if the bulbs are all identical, then that difference should be the same, too.

c) Here's a harder circuit, with resistors (like the ones you used in lab) instead of bulbs. What is the voltage across each of the resistors?



I should have stated here that the three resistors were identical. Assuming they are, the problem is a lot easier if they aren't. (But now that you know Kirchoff's rules you could do this with any values!) OK – now still think about that stuff flowing! How ever much current flows through A, it splits up and flows through B and C. Since B and C are identical again, they'd have the same current through them. (Should I have started all of these questions with the voltage and then asked about the current? It's easier to think about the current first!)

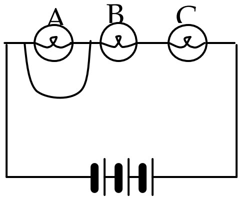
You also know that ΔV=IR: For a given resistance, the current is proportional to the voltage. So… if the current through B is half of the current through A, the voltage across B is half. Of course, the voltage from one side of the batteries to the other still has to be 4.5 V, so the voltage across A + the voltage across B (OR C) = 4.5 V.

That means the voltage across A is 3 V; across B and C is 1.5 V.

d) How would the currents through each of these resistors compare?

Already answered…

3) Back to the first circuit again. What if you were to connect a wire from one side of bulb A to the other, as I've shown here? How would that affect the voltages across and currents through bulbs A, B, and C?

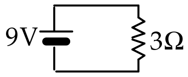


Before the wire is connected, we already know the answer: The voltage across each bulb is 1.5 V. But putting the wire in gives the current a no-resistance route around bulb A, so there's no loss of electrical pressure for the current making its way to the left side of B. So all of the 4.5 V is across B and C: 2.25 V each.

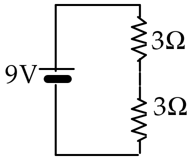
4) You've started to study the relationship between the voltage across a circuit element (a resistor, a light bulb, a bit of goop, whatever!) and the current that goes through it. For some materials, it's a linear relationship: The voltage and current are proportional. That's Ohm's Law (and thus the units of proportionality constant were called "Ohms "). (Ohm's Law is not really a law! Coulomb's Law is a Law – a foundational principle that underlies everything we're doing – our model depends on the idea that it *always* holds. Ohm's law is an empirical relationship that we find *usually* holds not always. We should really call it "Ohm's Empirical Relation" or something like that.)

So: V=IR, where V is Voltage (in Volts), I is current (in Amperes), and R is Resistance (in Ohms). Use Ohm's Empirical Relation to find the current through each of the resistors in these circuits.

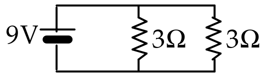
a)



b)



c)



I should have said, Ω is the symbol for "Ohms," but you probably figured that out. Argh – and I just noticed I've used the same symbol for "voltage" as a variable and "volts" as the unit: In V=IR it's the variable, in 9V is the unit, which makes for the absurd looking V=9V What a pain. I'll start making it ***V*** for the variable. So it's ***V*** = *IR.)*

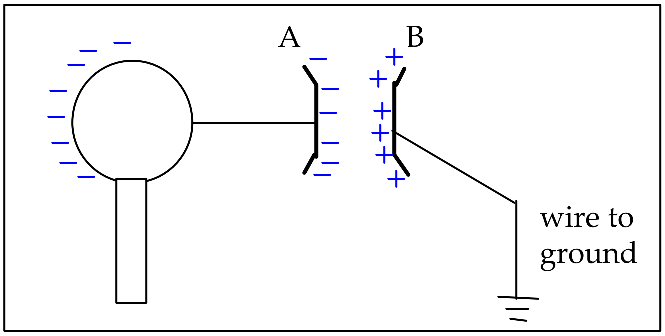
a) 9 Volts = I(3Ω), so I = 3 Amperes.

b) Now… we know the same current goes through each resistor, and we know the voltage across both must be 9 Volts. So the voltage across each resistor must be ***V*** =4.5 Volts. So the current in each resistor is ***V*** /*R* = 4.5 V/3Ω = 1.5 Amperes. Notice that's the same as if it were a single 6 Ω resistor with the 9V battery.

c) This time, we know that the voltage across each bulb is 9 V – there's no loss of electrical pressure as current flows in the wire, only when it goes through a resistor. So each resistor has a current of 3 Amperes through it!

Notice that means that the current coming out of and returning to the battery must be 6 Amperes! So as far as the battery is concerned, having those two resistors in parallel is like having a single 1.5 Ω resistor. And there's a place to stop and think about whether and how that fits with common sense – adding a second resistor makes the current flow *easier*? Sure! It's like putting another straw in your mouth to blow out the air.

5) Suppose you had a pie plate connected to a Van de Graaf generator by a wire as shown. A second pie plate is brought near the first and is connected by a wire to the ground. (Remember, for ground, think "huge, huge conductor.") Assume that it is a really dry day and that there is not much charge flowing through the air.



a) Draw a diagram showing where the charge will be while the generator is running.
The VdG would get a negative charge on it, and the wire would give a route for negative charge to move off onto the aluminum plate. So the distribution ought to look something like that on the VdG and plate A, the excess negative charges trying to get as far away from each other as they can.

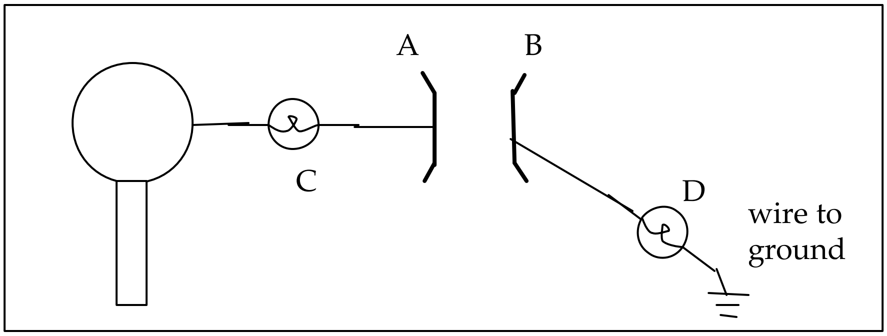
And the excess negative charges on A would push negative charges away from plate B—they can run out through the wire into ground—leaving excess positive charges.

b) Do the excess charges on the two pie plates have the same sign or different signs, and is there about the same amount of charge on the two plates or is it different, and how? (Does A have more or B?)
Opposite sign, for the reason above. They should have *about* the same amount of charge: A little negative charge sitting on B will be pushed down the wire by the negatives on A until there are about as many positives on B pulling it, keeping it from going down the wire. Still there should be a *little* more excess charge on B, since by Coulomb's law the force is stronger if the charges are closer, so the fewer positives are necessary to pull as hard as the negatives far away. [Note that the closer the two pie plates are to each other, the smaller this difference is. If they were almost touching the two charges should be almost identical, according to our model.] If you are really thinking, you'll also ask yourself, why the logic doesn't work the other way around. If there is more negative charge on A than positive on B, doesn't a negative charge on A feel more pushes from the other negatives on A than pulls by the positives on B? Yes, definitely, but for A, there are also pushes from the negatives on the generator, whereas for B, the repelled charges can get much farther away. Remember, think of ground as a HUGE conductor.

c) If pie plate B were much further away, how would that change the amount of charge on A and on B? If B were much closer (but still not touching and still not close enough to make a spark), how would that change the amount of charge on A and on B?

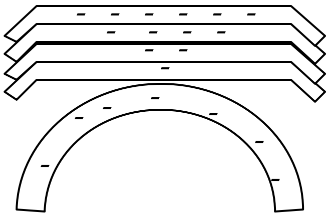
As I said above, as the plates get closer, the charges get more balanced as they get closer and less balanced as they get farther away. As they get farther away, there will also be less charge on both A and B. For B this is obvious, if it gets really far away, eventually, the force from the negatives on A is so small that it can't really move much charge around in B. Same for A, the farther B is away there is less "help" keeping the negatives together on the plate. One way to state all this is that, by our model, the effect that A and B have on each other just gets smaller with distance. It also gets larger with less distance, and as the plates get closer, they each will get more and more excess charge. An electron on the generator will see lots of negatives around it on the sphere and kindof a neutral object in the close pair of plates, and go there.

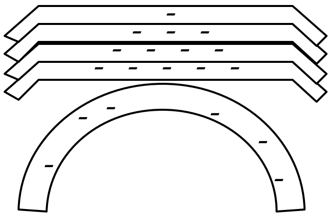
d) If before you turned the generator on you hooked up light bulbs at positions C and D, and then turned on the generator, would either of the bulbs light? Which one(s)?

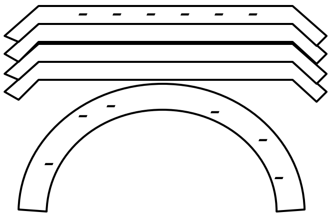


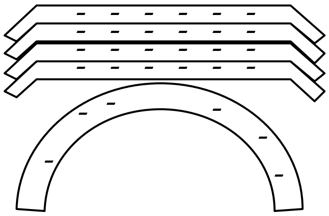
Charge is moving in both wires, which is current, so that *will* light the bulbs.

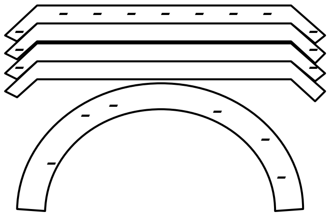
6) In class we discussed 5 possibilities for the arrangement of the charges on the pie plates when they are sitting on the charging Van de Graaf generator.


Idea 1


Idea 2


Idea 3

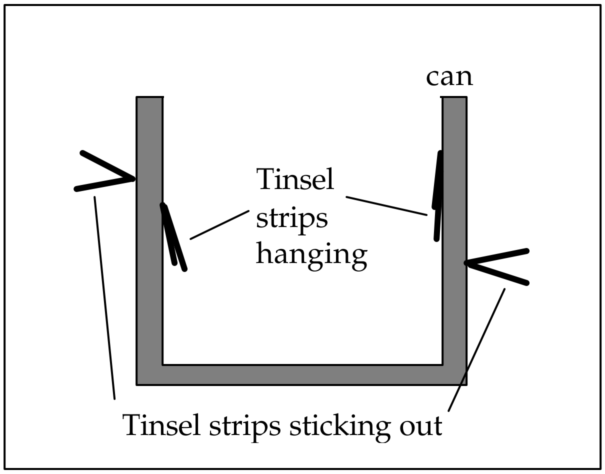

Idea 4


Idea 5

Trying to see which ideas explained our observations, we decided that all would predict a repulsive force on the top pie plate, but that number 2 and number 5 would predict that after the first pie plate came off, the next ones would come off immediately, which was different from what we saw.

In Joe Redish's 122 class last week, he showed the following demonstration. He had a can with several small pairs of tinsel strips stuck in different places. When he charged up the can with a generator, the tinsel on the inside of the can didn't stick up, but the tinsel on the outside did, as shown below (the can is shown in cross section.)

a) Explain why the tinsel did this and which of the ideas for the pie plates fits with this observation.



When the can is charged, the charges try to get as far away from each other as possible by all going to the outside surface of the can. In places where there is tinsel, the charges go onto the tinsel. The charges on the tinsel is the same sign for each strip and the same as the can, so the tinsel strips repel each other and the can and stick up. Inside the can, there is no charge on the can and thus no charge on the tinsel.

This observation agrees with the reasoning behind idea number 5, which is that the excess charge will go to the outer edges of the surface. This is in disagreement with ideas 1, 2 and 4, which relied on the idea that charge would distribute itself somehow through the inside of a conductor. This observation is also in disagreement with number 3, which said that everything between the top plate and the generator would act like a conduit and not charge up. The can here charged up on all of its outside surfaces. Note that number 5 is also the one that agreed fully with our model, which said that the charges repel (and thus want spread out as much as possible on the outer surfaces) and that the conductors allow them to do so. All of the other explanations (even the ones that couldn’t explain what we saw) used good intuitions and parts of the model, but sometimes relied on ideas that weren’t exactly what the model says, like charge spreading evenly inside an object or that a conductor that acts like a wire stays neutral, or that there’s something special about the top and the bottom of a surface, perhaps.

b) In class on the 11th, we also started talking about the arrangements of charges over a conductor being driven by an electrical analog to pressure. What does this say about the different ideas for the pie plates?

Lots of ways you can think about this. One is, why is there pressure? Because the like charges are all repelling, trying to spread out, which gives you idea 5 if you are careful. The analogy might lead you astray if you think it's *exactly* like air. Air under pressure will expand to fill a volume, more like idea 4. But again, that contradicts our model for charge if we think about it carefully. And if we are going to contradict our model we'd better do it for a very compelling reason, because if we do modify it we have to go back and make sure the new modification is consistent with EVERYTHING we've done before.

7) In this class, we've been trying to get across the value of considering different analogies for electricity. How are we doing so far? In what ways do you see this as useful and in what ways do you think it is not? [Note that what I'm trying to do here is to get feedback from you as well as to get you to reflect a bit on what you think of all this. Thus, you will only be graded on your thoughtfulness, not in any way on what we might want you to say. Please be honest!]

I've been impressed by how skillfully you guys have been using the analogies to make sense of the circuits, so I hope that that's because you see them as useful. I know I find them useful for myself, both for communicating with you guys and also for my own understanding. It really is difficult, or rather impossible, to understand these concepts without a bunch of these different ways of thinking about things. It's just important to keep in mind the limitations, and always check your understandings from the analogies with the more precise (but less intuitive) model that we state through mathematics and rules.