

University of Maryland
Department of Physics

Spring 2003
Physics 122

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March 6, 2003

Exam #1

Answer all questions on these sheets. Please write clearly and neatly: We can only give you credit for what is on the paper! Put your name and section number on every page.

There are two kinds of problems. The first set of questions is multiple choice. There's no partial credit for these – just choose the best answer and indicate it clearly. This doesn't mean that words or pictures won't help you! And they will help me in figuring out what feedback to give you.

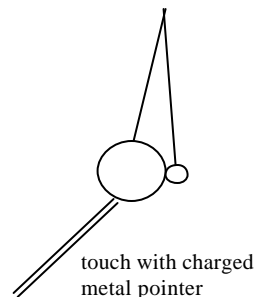
For the last set of problems, you need to show your reasoning, in words and/or mathematics. **These problems all require explanation.** Full credit is for a correct answer with a clear explanation. You'll get partial credit if we can understand and see the physical sense of what you were thinking. But you'll get no credit at all, regardless of the answer you give, if we can't follow your reasoning.

If you are unclear about what a question is asking, ask me! If there is something I can't tell you, I won't tell you, but it doesn't hurt to ask!

Multiple choice questions. No explanations; no partial credit. (8pts each.)

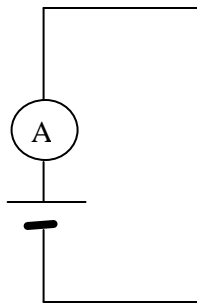
- 1) Two aluminum balls hang, neutral and in contact with each other, from non-conducting strings. One is much larger than the other. Suppose we touch the larger ball with a charged metal pointer (holding the pointer with an insulating handle), and then take the pointer away. In the end, compared to the large ball, the smaller ball would have

- a) smaller net charge, same voltage.
- b) smaller net charge, lower voltage.
- c) same net charge, same voltage.
- d) same net charge, lower voltage.
- e) equal and opposite charge, opposite voltage.

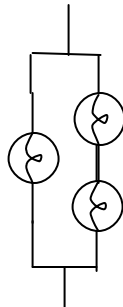


Our ideas from class say that conducting objects in contact come to the same pressure/voltage, just like the balloons did or the air in any large box will. Same voltage means less charge on the smaller ball because it would be harder to squeeze the like charges into the smaller area. Another way to think about this using the ideas in our charge model is that the like charges are repelling each other. The way for them to get farthest apart is to spread equally on all outside surfaces. The small ball has less surface area, so it will get less charge.

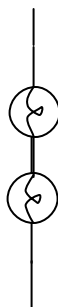
2) Suppose we have a battery connected to an ammeter, and we're going to connect it to a bunch of different light bulb configurations and measure the current for each. Rank these according to current, from highest current to lowest.



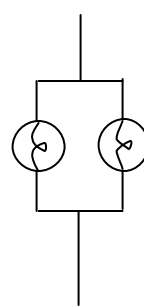
1)



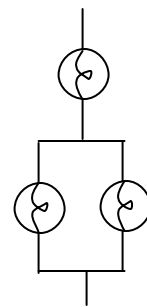
2)



3)



4)



5)

a) 2, 5, 3, 4, 1

c) 1, 4, 3, 5, 2

b) 4, 2, 1, 5, 3

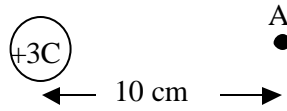
d) 1, 4, 5, 2, 3

e) 4, 5, 2, 1, 3

There's a bunch of ways you could approach this one, too. I won't talk about equivalent resistance because we didn't do that in lecture or much in homework. Also, I tried to make the choices such that you wouldn't fall in too many pitfalls. So, just thinking it through, you might first look to the smaller number of bulbs to give you the highest current. So you might think number 1 has the highest current. But then you remember that if you look at the voltages across the two bulbs in 4, each have the same voltage drop as the bulb in 1. So each bulb must have the same current as the bulb in 1, making twice the current through the ammeter in 4 as in 1. And similarly, the left bulb in 2 has the same current as the bulbs in 1 and 4, but the right two bulbs will have half that current because voltage drops over each of these two bulbs will be less than over the left bulb (or you could just remember the two bulbs in series were dimmer or that a longer straw = less current.) Soooo, the currents in 2 add up to less than 4, but more than three, so at this point you know that the answers must have the order 4,2,1. (choices b or e) What about 5? Will it have more current or less than 1? Well it must be less, since the top bulb doesn't have as much voltage drop as 1 (if it did, there would be none left for the bottom bulbs) and the current through the top bulb is the total current, so it must be less than 1. So now you have 4,2,1,5 which means you have to choose b. Does this make sense? Is 3 less than 5? One way to think about this is to realize that the bottom bulbs are parallel which is like two straws next to each other, so more total current can flow. Or you could try a simple calculation. The voltage drops across the top bulb of 5 plus the drop across one of the bottom bulbs must equal the battery voltage, and the current splits evenly in the two paths. So if the battery is 5V, $5V - IR - IR/2 = 0$ gives you $I = (10/3 V)/R$. In 3, $5V - IR - IR = 0$, giving $I = (5/2 V)/R$, which is less. You could have done this type of calculation for all of them pretty quickly, actually.

3) What is the electric field 10 cm from a +3 coulomb charge?

- a) About 9×10^{14} N/C
- b) About 3×10^{14} N/C
- c) About 9×10^{12} N/C
- d) About 3×10^{12} N/C**
- e) It cannot be determined from the information given.

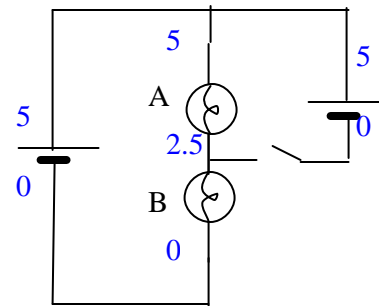


This one was kind of hard because you hadn't worked it out like this on homework.

The electric field is $E=F/q$, the force per unit charge. This tells you all the info you need to know so that when you find out what charge is there, you can get F easily. If you had a charge q at A, $F=k(3C)q/r^2$, and $E=F/q$ is just $k(3C)/r^2 = (9 \times 10^9 \text{ Nm}^2/\text{C}^2)(3 \text{ C})/(.1 \text{ m})^2 = \text{about } 3 \times 10^{12} \text{ N/C}$

4) So here's the circuit puzzle again from your homework. Now suppose that there was only a single battery in the first loop. The batteries are identical. When the switch is closed as shown, what happens?

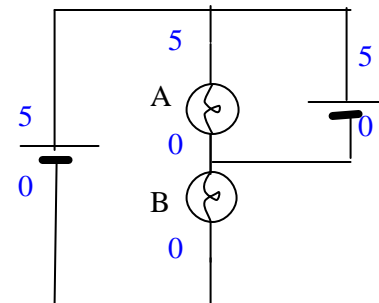
- a) Nothing happens (both bulbs are the same as before.)
- b) Bulb A gets brighter, and B stays the same.
- c) Both bulbs get brighter
- d) Bulb A goes out.
- e) Bulb B goes out.**



This one should be approached similar to the one on the homework.

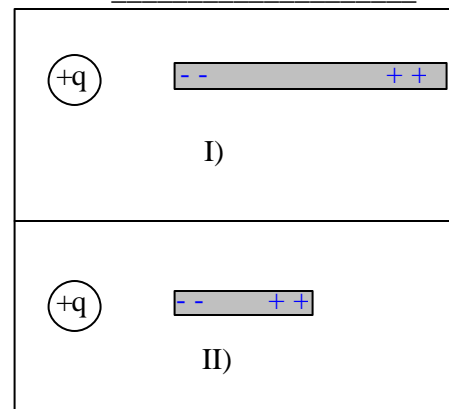
Suppose the batteries are 5 volts and you call the voltage in the top wire 5 V. Then all the wires connected to the top of both batteries and at the top of bulb A are at 5 V since all conductors touching each other have equal voltage (see number 1!!!) This is true with the switch open OR closed. Similarly, the wires touching the bottom of the left battery are at 0, including the bottom of bulb B and the wire touching the bottom of the right battery is also at zero. (True regardless of switch.) However, with the switch open, we don't know just from the rule about conductors what the voltage is between the bulbs. But with the switch open the current through the bulbs is equal and they are identical and the drops must be identical, so the voltage in between is 2.5.

With the switch closed, we know by the conductors touching rule that the wire between the bulbs is at 0 volts now, which means the drop across B is now zero, so it would have no current - the bulb would go out. A would also get brighter since now it has twice the voltage drop and twice the current. Current would flow through the switch this time but not through the left battery.



5) Consider the following two situations with a charged object and a metal rod. Think about the net force on the charged object in the two situations.

- a) There would be more force on the charged object (+q) in situation I than in situation II.
- b) There would be more force on the charged object (+q) in situation II than in situation I.
- c) There would be no force on the charged object (+q) in either situation.
- d) There would be the same (nonzero) force on the charged object (+q) in both situations.



There is an attractive force from both rods on the charged object because some positive and negative charges will separate on the rod. The negatives attract more strongly than the positives repel because they are closer to the charged object, leaving a net attractive force. In II) the separated charges are separated by less distance and so the difference between the attractive force and the repulsive force is less, leaving less net force.

- 6) Two identical charges +q are a distance L apart. Is it possible to place a third charge somewhere, such that none of the charges experiences any net electric force?
 - a) Yes, a charge -2q, in the center.
 - d) Yes, a charge -q/4, right in the middle.
 - b) Yes, a charge -q, in the center.
 - e) No, it's not possible.
 - c) Yes, a charge -q/2, in the center



If we place whatever charge we choose right in the middle, as shown, it is obvious that it will feel no force due to symmetry. The -q/4 charge here feels attracted to the right by the right +q and attracted equally to the left by the left +q, so these forces cancel, leaving no net force on the middle charge. What about the other charges? The left +q feels attracted to the right by the -q/4 with $F=kq(-q/4)/d^2=-kqq/4d^2$. It also feels repelled (pushed to the left) by the right +q with $F=kqq/(2d)^2=kq(-q/4)/d^2$. These forces are equal and opposite and cancel, as do the forces on the 3rd charge. If you were thinking a) you may have been thinking you'd need the opposite total charge to get no force. For b) you might have been thinking forces balancing, but forgetting about distance effects and for c) just forgetting the distance is squared.

- 7) A hollow metal sphere is electrically neutral (no excess charge). A small amount of negative charge is suddenly placed at one point P on this metal sphere. If we check on this excess negative charge a few seconds later we will find one of the following possibilities.
 - a) All of the excess charge remains right around P.
 - b) The excess charge has distributed itself evenly over the outside surface of the sphere.
 - c) The excess charge is evenly distributed over the inside and outside surface.
 - d) Most of the charge is still at point P, but some will have spread over the sphere.
 - e) There will be no excess charge left.

Our model says like charges repel, so that implies they want to get as far from each other as possible. That means spreading out over the surface. It might not be obvious that they will only spread to the outside surface, but that is something we learned in homework by considering the can and tinsel demonstration.

Long Answer questions. Partial credit will be given.

- 8) (10 pts.) In class we decided that for resistor made of a material with a resistivity ρ , the resistance would be given by $\rho l/A$. What does this equation mean and why does it make sense?

Mathematically, this equation means that as the resistivity of the length increases, so will the resistance, but that the resistance decreases as the cross-sectional area increases.

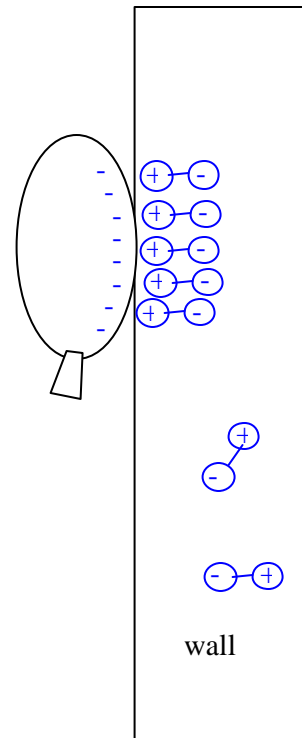
This makes sense because we've seen with several analogous situations that these trends are true. With the straws, it is harder to blow air through them the longer they get and easier the wider the straws are. With rainsticks, if you lift the end to a certain height (like constant pressure or ΔV) more current will flow, implying less resistance, if the rainstick is wider and less will flow if the rainstick is longer. Also, the higher the density of pegs in the rainstick (like ρ) the less current will flow (more resistance.)

- 9) (14 pts) When you rub a balloon on your head, on a dry day, it will stick to the wall as shown. Explain why it sticks, drawing on the picture to show what's happening.

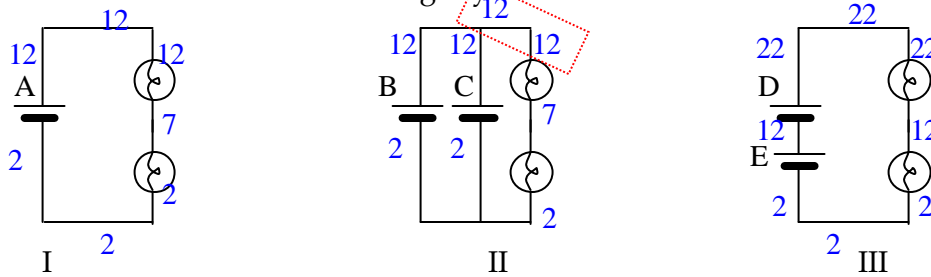
We know that rubbing doesn't create charges but can move them apart, so we can assume an excess charge is created on the balloon (and an opposite excess charge on your head.) So that we can draw something, let's assume the balloon becomes negative.

I told you to assume the wall was made of plastic or wood because we'd had plenty of experiences in class with plastic as an insulator. This means, of course that charges cannot move within it. (If it was a conductor and charges could flow easily, you would never build up a charge on the Van de Graaf or the discharge sphere!) If the balloon touches the wall, some of it's charges can move on to the wall (since insulators can let charge on and off, just not let it move around within). So a little bit moves on to the wall, only at the contact point. This creates a repulsive force, but it's small since so little charge transferred, and we don't have to worry about it.

So the charges in the wall feel the force from all the negatives on the balloon, but they can't move around within the wall because it's an insulator. But something must happen to create the force, so we can assume the wall has dipoles that can rotate. The dipoles turn so that they're positive ends are toward the balloon and the negative ends away. Thus the attractive forces between the dipole's positive ends and the balloon are a little stronger (because they are closer) than the repulsive forces between the balloon and the negative ends of the dipoles. So there is a net attractive force.



10) (20 pts.) All the bulbs are identical and the batteries are identical. a) In which circuit(s) would the bulbs shine the most brightly?

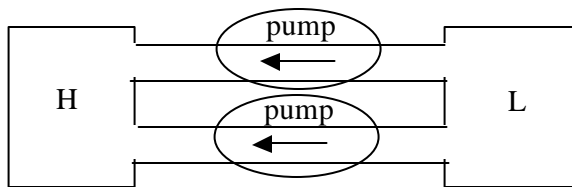


To look at voltages, let's assume that the bottom wire in each case is at 2 V. Then we can follow around all the wires connected to this and make them 2 V as shown. Also, we can determine the voltages on the opposite sides of the batteries if we know the battery voltages. Let's call them 10 V. Thus all the regions shown as twelve. For case III, the voltage above the second battery is now 22 and all the wires connected to it are at 22.

One of the common mistakes I saw folks making was adding up the voltages of the batteries in II so that the voltages in the red dotted box were twice the battery voltage. But our rules say that all conductors touching each other have the same voltage!!! So the extra battery doesn't impact the voltage across the two bulbs. Note that if the batteries in II had been different voltages, we wouldn't have known what to do! The rule about conductors touching would have been impossible to apply, and the loop rule on the loop with both batteries would also have failed. You wouldn't have gotten $\sum \Delta \neq 0$. That's because we would have violated one of our assumptions, which is that batteries maintain their stated voltage difference. If we put two different batteries in parallel they can't both do that.

If you thought that the batteries in parallel will add voltage, we see that this violated the conductor rule (and the loop rules, incidentally, which, if you do the right loop of II is just like I. But also, if you thought this you were failing to ask yourself, "But they're hooked up different - shouldn't that make a difference?"

Plus, thinking of analogies could have helped here. If you have two pumps in parallel, and each is only going to pump so as to make the pressure difference low to high, it doesn't matter for the pressure that there are two pumps there since each one is only going to turn on just enough to maintain low to high.



Anyway, looking at our voltages we see that the voltage drops across the bulbs in I and II are the same, which implies the same current through the bulbs and same brightness. The drops in III are twice as high, so twice the current, more brightness.

b) Suppose you hooked up these circuits with brand new batteries and labeled them A-E as shown. If the bulbs are identical and never burn out, which battery(ies) would last the longest. Why?

Thinking about the power dissipated... If the bulbs are each 1Ω , The currents in I and II will be 5 Amps and in III 10 amps. Thus the power through the bulbs in I and II is $\Delta \mathcal{A} = 10V(5 \text{ amps}) = 50$ Watts. Battery A is providing 50 Watts of power and batteries B and C are providing 50 Watts total. Lets assume B and C each provide 25 Watts. (In the air pump analogy the two pumps both spend more time off with both connected.) So B and C will last longer than A.

In circuit III, the power is $\Delta \mathcal{A} = 20V(10 \text{ amps}) = 200$ Watts, and batteries D and E must each provide 100 watts, so they'll die before A and long before B and C.

[Note I was only expecting you to figure out that B and C lasted longest. You didn't need to do the power calculations to get full credit. BUT, if you were thinking of how long they last as being tied to the current, don't forget that the power is not linearly proportional to just I.]

Another thing to notice is that, if you were one of those who that two batteries made a difference and decided that the bulbs in II were brighter than in I, here's a way to refine your intuition. Having more batteries did make a difference - not in how bright the bulbs were but in how long the batteries lasted!!!