HW9 Concepts

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1 24.28 Capacitor Energy

You are told to consider connecting a charged capacitor together with an uncharged one and told to compute (a) the original charge, (b) final potential difference across each capacitor, (c) the final energy of the system, (d) the decrease in energy from the original, (e) and to speculate on where the energy went.

So, this problem is a rather straightforward application of the rules we have learned for capacitors so far. Some things to think about. How does the original charge compare to the final charge? How do the potential differences across the capacitors compare? Could we have expected this? And then once you compute the final energy and energy difference, you are told to speculate on where the energy went. I think this is actually a rather deep question. See if you can come up with a good answer and justify it to yourself. Does your explination make sense? Are you convinced of its validity? Are there any related problems you think should be explored to get a better handle on the energy flows in this setup?

2 23.32 Metal Sphere Potential

You are told to consider a metal sphere with some radius and with charge distributed on its surface. Then you are told to compute the potential at various locations.

Do the values you compute make sense? Do they agree with your notion of potential as 'work per unit charge'? You are told to compute the potential at a single location, yet we discussed potential in circuits as always being between two locations. Were we not being general enough, or there some implied starting location in this case? What location is that? What do you get for the potential for the point inside of the sphere? What can you say about the potential at other points in the sphere? Does that make sense? Can you reconcile this with what you know about the electric field inside the sphere? I suggest you make a graph of the potential everywhere for this problem and try and make sense of its shape. Are there any discontinuities? Do you expect any distribution to create discontinuities in the potential? Under what conditions could this happen? Does this make sense given our notion of potential as 'work per unit charge'? If there were disconuities, in the language of work per unit charge, what would this mean?

3 23.35 Potential of a Wire

You are told to consider a very long wire with uniform charge density λ. Then you are given some readings from a voltmeter put at different locations. First you are told to calculate λ, and then you are told to answer some questions about what would happen if we move the probes.

So here again, if we are considering using a voltmeter, we need to have two probes to specify a potential. Why then in the previous question were you told to calculate the potential at a single point? How are you going to figure out λ given the potential at two points? If you used an equation for the potential due to a line charge from the book, make sure you pause to think about where the result came from. Look at its dependencies and limits and see if this makes sense. Try and derive it again yourself, or follow the derivation in the book. In answering parts (b) and (c) if you plugged numbers into an equation, stop to think about whether you could have answered these parts without plugging in numbers. Can you reconcile the results with your notion of what electric potential is? The problem says we have a very long wire, but not an infinite one. Does this introduce any subleties into your answers? If the wire had some finite length L, at what distances from the wire do you expect your equation to break down?

4 23.12 Proton Collision

You are told to consider two protons that are aimed directly towards each other. You are told to calculate the maximum electric force that the protons will exert on each other.

First convince yourself that there will be a maximum force that they exert on each other. Why is the maximum force not infinite? What will the protons be doing when they are exerting the maximum electrical force on each other, at what point does this occur in the motion, and where are they located relative to each other at this time. What are they're speeds at this time? How can you relate their initial speeds to the maximum force they will exert on each other? Are you relying on any conservation laws? Does your answer depend on how far apart they are from one another initially? See if you can picture the whole motion from start to end.

For an interesting follow-up, whats the distance of closest approach for the protons, and how does this compare to some distances you know?

5 23.49 Two Spheres

You are told to consider two metal spheres with different radii with one embedded in the other, and then told to compute the potential everywhere. As a hint they tell you that the potential for this system is the sum of the potentials due to each sphere alone. Why is this true? Is this true in general? You are told to take V to be zero at infinity. Why do you they need to tell you this? What does this mean. Once you have calculated the potential in the three regions, graph it and take a look at the shape. Could you have expected this kind of behavior? In part (b) you are told to show that the potential of one sphere with respect to the other has a particular form. What does that mean, the potential of one sphere with respect to the other? Can you think of a way to measure this in the lab? Does its form have a form you could have expected? Does the hint they told you hold true for this equation? Why or why not?

So your problem set only asks you to do parts A and B, but I think it would be helpful to work the remaining parts as well, below is my discussion of these: Having found the potential, now you are told to calculate the electric field between the spheres using equation (23.22)

$$\vec{E} = -\vec{\nabla} V$$

What is the relation between the electric potential and the electric field. Make sure you understand this relationship. What is the corresponding equation to (23.22) but in the other direction, i.e. if $\vec{E} = -\vec{\nabla} V$, what does V equal? Make sure you understand this relationship.

You were told to calculate the potential first and the field second, could you have done them in the reverse order? Does it make sense? Would one of these ways have been easier than the other? Why?

Now you are told to repeat this process for the electric field outside f the larger sphere. Does this electric field have a form you should have expected?

Now you are told to consider the case where the charge on the outer sphere was not $-q$ but some other magnitude $-Q$. You are told to show that (b) and (c) would be the same but (d) would be different. Why? No really, why?

6 23.85 Nuclear Fusion in the Sun

In this problem you will explore a model of how the sun works. You are told that for nuclear fusion to take place, the protons must come into 'contact' with each other. In part (a) you are told to assume that they are moving head on and are given a value for the radius of a proton. What is the minimum speed that would allow for fusion to occur? This is an application of the results from problem 23.12.

You are next given some more information about protons. You are told their charge distribution is spherically symmetric and their mass. In part (b) you are told to repeat this calculation but this time not for protons but for helium nuclei.

Next in part (c) you are reminded of the result of the equipartition theorem, namely that the average kinetic energy of a point particle is $\frac{3}{2}kT$ with k the Boltzmann's constant and told to compute the temperatures required to see the kinds of collisions you considering in parts (a) and (b). In parts (a) and (b) we assumed these particles were headed for a head-on collision, but surely the gas inside the sun doesn't all move in the same direction. How do you think you would have to modify your answers if we wanted to be a bit more realistic.

Furthermore, we are told to consider these processes for protons and helium *nuclei*. I was always told that the Sun was made up of Hydrogen and Helium. Why are we doing this for the nuclei only? What happened to the electrons? (Remember the sun is very hot).

Next you are told the temperature in the Sun's core and told to compare this with your results. How do they compare? Can you explain any discrepencies? Is our model of the sun wrong? You are told to look at the discussion of molecular speeds in Section 18.5. Review this, but the basic idea is when we say the average kinetic energy of molecules in a case is $\frac{3}{2}kT$, are we saying that all molecules move with the same speed? See if you can estimate the fraction of nuclei that would be involved in these processes? Which fusion process do you expect to be more likely, the proton fusion or the helium fusion?

7 24.8 "Design-A-Cap"

You are given some specifications for a new capacitor to be built. You are given the desired capacitance, and maximum potentials, with a limit on the desired electric field strengths. Then you are told to give its physical dimensions and told to calculate the maximum charge the plates can hold.

How will you determine the dimensions? Are they're any free parameters left after the above considerations? What sort of dimensions do you obtain, are these realistic dimensions for a capacitor? You are told to calculate the maximum charge the plates you've designed can hold. What determines how much charge they can hold? What sets the limit? What are we concerned about happening? If we were additionally interested in maximizing this maximum charge, how could we accomplish this? Do we have any freedom left over from our above constraints?

In addition to the problem in the book, you are told to repeat the problem if instead of having our capacitor air-filled we were to have it filled with polyester. What's going to change in this case? Do you think the capacitor should be air-filled or polyester-filled or something-else-filled at the end of the day?

8

In this problem you are told to revisit Examples 23.4 (page 792 in my copy) and 21.9 (page 728 in my copy). You are told to calculate the electric field at the three locations a,b, and c given the potential at those points. In example

21.9 the book calculates the electric field at all of the points. In example 23.4, they calculate the potential at each of the points. What they want you to do, is using the results obtained in example 23.4, compute the electric field at the points a,b, and c. How are you going to do this? Could we have gone in the opposite direction? Can you use the electric fields from example 21.9 to obtain the potentials at the points?

Make sure you understand the connection from the electric field to the potential, and the potential to the electric field. Is one of these directions easier than the other? Why? If I gave you a charge distribution, would you rather calculate the electric field everywhere, or the potential everywhere? Why do you perfer one over the other?

9 Smile!

This problem is similar to the Design-A-Cap above. We are given specifications for the energy we want to dissipate, and the resistance the capacitor is connected to, as well as we are told we want to dump 95% of the energy in 3.0 seconds.

First you are told to compute C. Which of the specifications do you need to use to find C? What does the requirement that 95% of the energy be dumped in 3 seconds have to do with the time constant of an RC circuit?

Next you are told to compute the potential we should charge the capacitor to. You are asked if this potential can be achieved with household batteries. Can it? Why or why not? If you said no, try to consider how the camera accomplishes this. Most cameras run off of two 1.5 Volt batteries.

Finally you are told to compute the total charge on the capacitor, and consider whether or not this is a large amount. For comparison, consider calculating the charge on some of the capacitors you encounted in your lab last week. Why don't we have large lightnight bolts? How does the camera contain this amount of charge?

As a follow discussion. Many students have experienced the shocks associated with one time use cameras. I can't advocate you try this, but most of you probably know what I'm talking about. What sort of shock can cameras generate? Which of the parameters (Voltage, Charge, Time Constant) make the shock feel so fierce? Or is it some other quantity in general?