Administrative Questions

Can we have homework solutions posted before recitation?

We discussed this among instructors, and Prof. Kruse decided that answers (not solutions, i.e. like back-of-the-book answers) will be posted before recitation. I think this will be starting soon.

If you want to check your full solutions before recitation, please come to office hours, Help Room etc.. I’m happy to help.

Can we have more space for writing on the quiz?

I’ll pass on this suggestion, but I think in general it should be possible to write the solution in the space given. If you need scratch paper, that is fine–please just ask for it!

Content Questions

Can you explain “grounding”?

“Grounding” a capacitor or part of a circuit means that you connect it to “ground”– this means a conductor that can be considered an infinite reservoir of charge. “Ground” can mean literally the ground, or some conductor connected to the Earth. If you ground a circuit, charge is free to flow on or off it, and the grounded part of the circuit will come to the same potential as the Earth. Often it’s convenient to take the Earth potential as $V = 0$ (although one can also add any constant value to it).

How do you deal with adding a dielectric to a capacitor?

Adding a dielectric between the capacitor plates increases the capacitance by a factor of $\kappa$. What happens then depends on the rest of the system: if voltage is held constant, charge on the capacitor will increase. If charge is held constant (capacitor is disconnected), the potential across it will decrease.
When you insert a dielectric, how can it increase the potential energy?

A capacitor with a dielectric between its plates has a larger capacitance, according to $C = \kappa C_0$, where $C_0$ is the original capacitance and $\kappa$ is the dielectric constant of the material.

Now, if this is done at constant voltage (i.e. with a battery attached), if the new capacitance is larger, then you can store more charge for a given potential difference. Since energy stored is $\frac{1}{2}C\Delta V^2$, and if $C$ increases with $V$ constant, then energy stored is increased. The energy doesn’t come out of nowhere: *work is done by an external agent* on the system. The battery is such an external agent: it pumps charge onto the plates in order to maintain the potential difference.

What does a dielectric do on a microscopic scale?

Dielectrics contain dipole charges that are not very free to move around, but can line up with an applied electric field. Between the plates of a capacitor, they tend to line up with the field in such a way that they themselves create an electric field opposite to the applied field. So the field between the plates decreases. The potential between the plates also decreases (assuming the charge is the same). So for a given charge, the potential difference decreases, meaning that the capacitance increases.

This is described in some detail in 26.7 of your text, with some nice diagrams.

If charge is constant (e.g. for isolated plates), inserting a dielectric will *decrease* the energy stored (potential difference decreases, and the system does work on the dielectric). This is the situation in example 26.5 of your text.

But if instead potential difference is held constant as the dielectric is introduced, such as when a battery is connected (as in your homework problem 68), what happens is that the system with dielectric now stores *more charge*; more work was done to put the charge there and hence more energy is stored. The *net* field between the plates is the same as before, if potential difference is the same; but with dielectric, the field due to the plates is bigger. The dipoles are aligned such that they are canceling some of the extra field due to bigger charge on the plates.
In homework problem 56, how did you draw the equivalent system?

In a circuit diagram, wires connect points of equal potential (in a conductor, the potential is constant). So you can take the inner charge plate of this problem and draw it equivalently as two plates connected by a wire. These two plates can then be drawn as the two top plates of two capacitors in parallel—the bottom plates of the capacitors are the upper and lower plates of the problem. These upper and lower plates are connected to ground, which we can define to have zero potential.

In homework problem 56, how did you get $\frac{1}{3}Q$ and $\frac{2}{3}Q$?

(See also above question). The top and middle plate can be treated as capacitor $C_1$, which has $C_1 = \frac{\epsilon_0 A}{d}$; the middle and bottom plate can be treated as capacitor $C_2 = \frac{\epsilon_0 A}{2d}$. $C_1$ and $C_2$ have the same voltage drop across them. Since $C_1 = 2C_2$, we must have the relation between the charges $Q_1 = 2Q_2$. We also have that $Q_1 + Q_2 = Q$, the total charge on the parallel capacitors. So $2Q_2 + Q_2 = Q$, or $Q_2 = \frac{1}{3}Q$, from which it follows that $Q_1 = \frac{2}{3}Q$. The charge on the outer plates will be negative.

In homework problem 74, what was $r'$?

This was the variable of integration. To find the capacitance, you need to find the potential difference between the wires, which is the line integral of electric field, $\Delta V = -\int_{r}^{r'} \vec{E} \cdot d\vec{l}$ along the line between the wires. The line element is a little element along the line between the wires, $dr$: I called it $dr'$, to distinguish the “dummy” variable of integration from the integral limit $r$. The electric field is a function of distance from the wire, $E = \frac{\lambda}{2\pi \epsilon_0 r}$.

The integral is $\Delta V = -\int_{r}^{r'} \frac{\lambda}{2\pi \epsilon_0 r'} dr'$.

How do you decide if capacitors are in series or in parallel? (like in the quiz problem)

Capacitors in parallel have the same potential difference across them. So for the case when dielectric fills the full gap distance but half the area between plates, you can consider that two capacitors in parallel, since one capacitor with dielectric and one capacitor without dielectric each have their top sides in contact, at the same potential; they also each have their bottom sides in
contact, at the same potential. So they each have the same potential drop between the plates.

Capacitors in series are hooked up back-to-back, so that they have different voltage drops across them, but the same charge. If you have the dielectric filling the whole area but only half the gap distance, this is equivalent to capacitors in series. The potential difference across the dielectric is different from the potential difference across the air gap.

**What is energy density used for?**

The energy density is the energy stored in a capacitor per unit volume, and comes out to $u = \frac{1}{2}\epsilon_0 E^2$, where $E$ is the electric field. It turns out this is a general expression that’s valid for more situations than just a parallel-plate capacitor. It tells you how much energy is “stored” in a region of space that has an electric field in it. Understanding of energy density and flow is critical for many applications in science and engineering, and many examples are coming up.

**In the lab, how do you find capacitance from the graphs?**

I haven’t seen this lab in action myself, but looking at the description, it looks like you are measuring potential energy (proportional to height) vs voltage on the capacitor. Since $U = \frac{1}{2}CV^2$, then plotting potential energy vs $V^2$ will give a straight line, the slope of which is $C/2$. You need to also account for efficiency of the motor (fraction of energy used) by measuring the ratio of work done (energy required to raise a mass) to energy consumed (measured using LoggerPro).

**Is charge for capacitors like current for resistors?**

Well... not really. But you can relate charge to capacitance with $Q = CV$ and current to resistance with $I = V/R$. So I guess you can say that $1/R$ is the proportionality constant between current and potential difference, and $C$ is the proportionality constant between charge and potential difference.

**Joke of the Week**

[I Enjoy Being a Battery](https://www.theonion.com) by A Nine-Volt Battery, from The Onion.