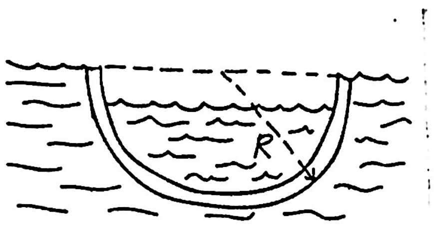
Instructions.

1. Complete this exam packet, and submit it to Gradescope before the end of the exam period, Saturday Aug 1st, 2020, 12:30am PDT.
2. Make sure all final work is in only the spaces provided, and make sure to upload a document of exactly the length of this packet.
3. If you are using a smartphone to generate a scan, please use a scanning app such as Adobe Scan to quickly generate an optimized PDF document.
4. There is extra space at the end of the packet in case the space below each problem isn't sufficient, but if you use that extra space, make sure to indicate that extra work is contained there when you show your work for a problem.
5. You are allowed to use the CCLE course page, the course textbook (OpenStax), and your notes, but you are not permitted to use any other internet resources.
6. A calculator (whatever type desired) is allowed.
7. You may not communicate about the contents of this exam with anyone during the exam period.
8. You may not logon to Campuswire during the exam period.
9. **Liz, Thomas, Kathryn, Alyssa, Utkarsh, and Mahfuzun will NOT be free to answer clarifying questions about the exam during the exam period.** If you believe there is an ambiguity, feel free to make a note of it to yourself and we will attempt to address it post-exam, but otherwise do your best to answer the questions based on what they say. There are always options for regrade requests on GradeScope.
10. Violations of instructions pertaining to what you are not allowed to do during the exam will be considered cheating and will be reported to the Dean of Students *and* the flexible-timing-based system for future exams in this course will be changed to impose stricter timing specifically to emphasize student independent work without consultation of outside resources beyond what is listed above.
11. After you complete your exam, come back to this page to sign and date your name below officially confirming that you have read and upheld these instructions. By signing and dating below, you are telling Liz that you affirm your ethical participation in this exam and your following of the above stipulations, on your word.

12. Your signature: [illegible]   Today's date: 7/31/2020

1. Some fluids.

1.1. Thomas partially fills a hemispherically shaped bowl with water, and finds that it floats in the surrounding water. When $4 \times 10^3 cm^3$ water is added to the bowl, the bowl just barely floats. The mass of the bowl is 0.6 kg. What is the out radius of the bowl? See figure below:



Archimedes' principle: $F_B = W_{fl}$

water mass: $4\times10^3 cm^3 \left(\frac{.001 kg\ H_2O}{1 cm^3\ H_2O}\right) = 4.0 kg\ H_2O$

$m_{tot} = 4.0kg + 0.6kg$

$m_{tot} = 4.6kg$

$\rho_{H_2O} = 997 kg/m^3$ $F_B = \rho V g = W_{fl} = m_{tot} g$

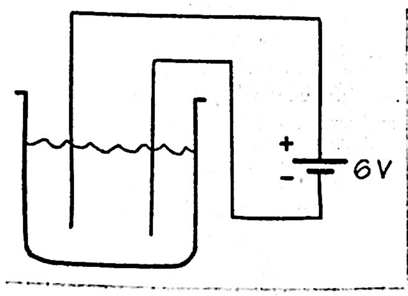
$V_{Hemisphere} = \frac{2}{3}\pi r^3$

$\frac{2}{3}\pi r^3 \rho = m_{tot}$

$\sqrt[3]{r^3} = \sqrt[3]{\frac{m_{tot}}{\pi \rho}\left(\frac{3}{2}\right)}$

$R = 0.130 m$

1.2. Thomas takes out the bowl, and decides to use the water with a battery to complete a circuit. Use the figure setup below. If the battery is 6-volts, and Thomas measures 50mA current to flow for 10 hours, how much energy is taken out of the battery at the end of his experiment?



$I = 50mA$ $t = 10hrs$ $V = 6V$

$= .05A$

$t = 10hrs\left(\frac{60min}{1hr}\right)\left(\frac{60sec}{1min}\right)$

$P = IV$ $t = 36{,}000sec$

$P = .05(6)$

$P = .30W$

$E = Pt$

$E = .30(36{,}000)$

$E = 1.08 \times 10^4 J$

2. Kathryn has a piece of plastic with unknown dielectric constant she wants to measure, and she has a capacitor and a battery on hand.

2.1. What can Kathryn do to experimentally determine the dielectric constant of her plastic?

Kathryn should first calculate the initial capacitance after charging her capacitor with air between the plates using the battery. She can calculate the capacitance by using $C = \varepsilon_0 \frac{A}{d}$, where ε_0 is the constant permittivity of free space, A is the surface area of the plates, and d is the distance between the plates. She then should insert the plastic so it totally fills the gap between the plates. She should then remeasure the capacitance. She now can calculate the dialectric constant by dividing the final capacitance by the initial.

$$C = kC_0$$
$$k = \frac{C}{C_0}$$

2.2. When Kathryn charges the capacitor without the dielectric, the voltage readout reads V_0. When Kathryn, keeping the capacitor connected in the circuit, slides the dielectric in, she takes a new voltage reading. Would you predict that the voltage is higher, lower or the same. Explain your reasoning. If you say the same, then describe what physical parameter changes and explain why it changes.

I would predict the voltage to be the same because the molecules in the dielectric will be arranged in a way so the dielectric will have a negative side which is attracted to the positively charged plate of the capacitor and vice versa for the other side. This initially decreases the voltage - the work to polarize the dielectric material between the plates uses up some stored electrical energy. Although, batteries mantian constant voltage. Therefore, the battery will create more charge displacement to balance out the voltage of the capacitor and the battery. This will increase the charge of the capacitor.

The capacitance will also increase since charge increases and voltage stays the same.

2.3. Kathryn redos the experiment again but this time unplugs the capacitor before adding in the dielectric. In this case, would you predict that the voltage is higher, lower, or the same. Explain your reasoning. If you say the same, then describe what physical parameter changes and explain why it changes.

I would expect the voltage to be lower because as the dielectric is pulled into the gap, the work to polarize the dielectric material between the plates is done at the expense of the stored electrical energy. This use of stored electrical energy is why voltage decreases in this case. (Dialectric pulled into gap because negative side of dialectric attracted to positive side of plate and vice versa).

This ultimately causes voltage to decrease, capacitance to increase, and charge to remain the same.

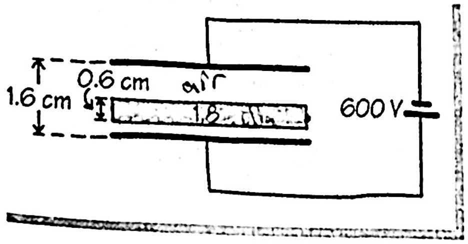
2.4. Given that Kathryn does not have a way to directly measure charge, nor does she know the exact capacitance of her capacitor, revise your recommendation for how she can find the dielectric constant of this material. Would you recommend Kathryn's first or second strategy to be more useful.

If Kathryn can't directly measure charge and she doesn't know capacitance, she should buy a voltometer to measure initial and final voltage. Kathryn should first charge the capacitor with air between the plates using a battery. Then when the capacitor is fully charged she should disconnect the battery and note the initial voltage. She then should insert the plastic so it totally fills the gap between the plates. She then should note the final voltage. The final voltage as a fraction of the original voltage is the dielectric constant.

$$V = \frac{1}{k} V_0 \qquad k = \text{dielectric constant}$$

I think that both strategies are good because they both ultimately give the dielectric constant, which is what we're looking for. But I would say the second strategy could be more useful because Kathryn could directly see how the dielectric lowers voltage.

2.5. Once Kathryn gets the dielectric constant, she calls it κ and hands it to Alyssa. Alyssa constructs a capacitor system that is part dielectric and part air gap, as shown in the diagram below. What are the electric fields in the empty space and inside the dielectric? You may use $\kappa = 1.8$ or you may leave it in variable form.



$V = 600V$ $k = 1.8$

$d = 1.6cm = 1.6 \times 10^{-2} m$

diaelectric thickness = d_2 = 0.6cm

$d_2 = 6.0 \times 10^{-3} m$

Parallel plate capacitor capacitance: $C = \varepsilon_0 \frac{A}{d}$

$C = \varepsilon_0 \frac{A}{1.6 \times 10^{-2}}$ $C = \frac{Q}{V}$

$Ed = \frac{Qd}{\varepsilon_0 A}$ $Q = CV$

$E_i = (\frac{1}{k} - 1) E_0$

$E = \frac{\left(\frac{A \varepsilon_0}{1.6 \times 10^{-2} m}\right)(600V)}{\varepsilon_0 A}$

Electric field w/o dielectric: $E = 3.75 \times 10^4 V/m$ (empty space)

$Q_0 = CV$

$E = \frac{Q_{dielectric}}{\varepsilon_0 A}$ $Q_{dielectric} = (\frac{1}{k} - 1) Q_0$

$= (\frac{1}{1.8} - 1)\left(\frac{A \varepsilon_0 (600)}{1.6 \times 10^{-2} m}\right)$

$E = \frac{(\frac{1}{1.8} - 1)\left(\frac{A \varepsilon_0 (600)}{1.6 \times 10^{-2} m}\right)}{\varepsilon_0 A}$

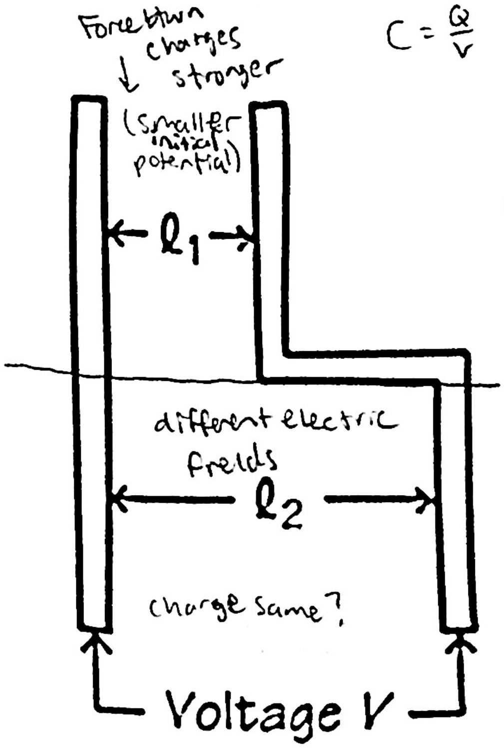
$E = 1.67 \times 10^4 V/m$ = Electric Field w/ dielectric

Electric field inside dielectric: EF w/o dielectric − EF w/ dielectric

$= 3.75 \times 10^4 V/m - 1.67 \times 10^4 V/m$

Electric Field Inside dielectric = $2.08 \times 10^4 V/m$

2.6. Mahfuzun doesn't have any dielectric, but finds a bent sheet and makes a unique capacitor, shown below. What is its capacitance? Would you say this capacitor resembles two capacitors in series or two capacitors in parallel? Explain your reasoning and connect your math to the important physical parameters in the problem.



$C = \frac{Q}{V}$ *different d

They both will experience full voltage of battery.

I think this capacitor would resemble 2 capacitors in parallel because when hooked up to a battery, a battery will try to mantain constant voltage between the capacitor and the battery. And 2 capacitors in parallel have constant voltage.

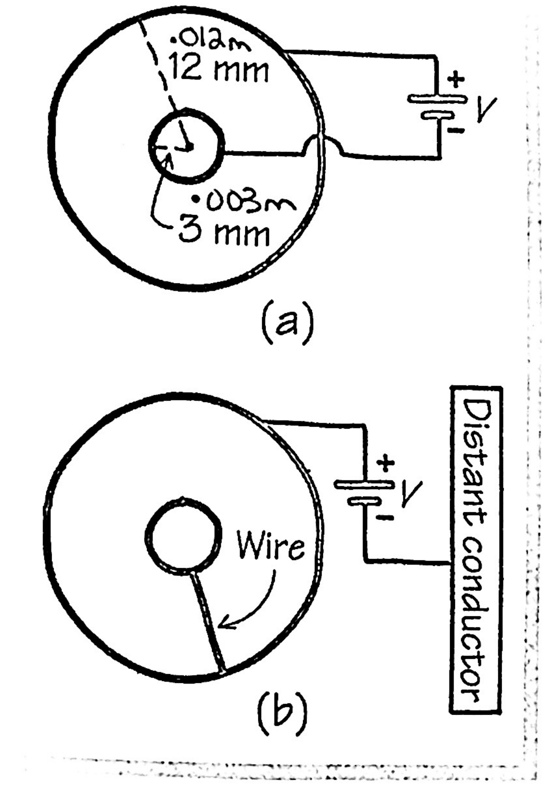
Although, the charges will be different to accomodate to constant voltage. And 2 capacitors in parallel have varying charge.

$$C_1 = \frac{A\varepsilon_0}{\ell_1} \qquad C_2 = \frac{A\varepsilon_0}{\ell_2}$$

$$C_{Tot} = \frac{A\varepsilon_0(\ell_1 + \ell_2)}{\ell_1 \ell_2}$$

2.7. Utkarsh makes a cylindrical capacitor as shown below. What is the capacitance, as it is constructed in the top figure? What is the capacitance as it is constructed in the bottom figure?

$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m



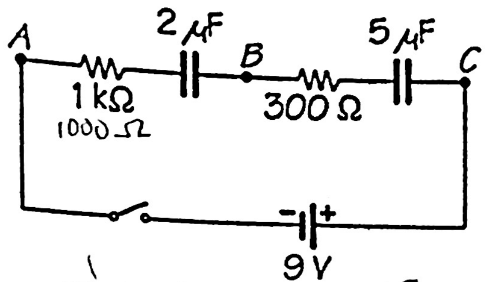
Capitance of cylindrical capacitor: $C = \dfrac{2\pi \varepsilon_0 l}{\ln(R_2/R_1)}$

$$C = \frac{2\pi \varepsilon_0 l}{\ln(.012/.003)}$$

$$C = (4.011 \times 10^{-11}) l \text{ F}$$

The capacitance of the bottom figure is 0 because it will short circuit. The current travels a low resistance path.

3. In the circuit below, Liz wants to figure out a few things about the potential at point B. Compute the potential difference between V_B and V_A (a) shortly after the closing of the switch and (b) a long time after the closing of the switch. Lastly: (c) How fast does the circuit reach a steady state (choose your criteria for establishing that steady state has been "reached.")



(a) ~~$\mathcal{E} = \frac{dW}{dq}$~~ ~~$I = \frac{dq}{dt} = \frac{V}{R}$~~

$R_{TOT} = 1000\,\Omega + 300\,\Omega$
$= 1300\,\Omega$

$\frac{1}{C_{Tot}} = \frac{1}{2} + \frac{1}{5} = \frac{5}{10} + \frac{2}{10}$

$\frac{1}{C_{tot}} = \frac{7}{10}\,\mu F = \frac{7}{10} \times 10^{-6}\,F$

$C_{tot} = \frac{10}{7} \times 10^{-6}\,F$

$V_{AB} = IR_{AB}$ $\quad I = \frac{V}{R_{Tot}}$ ← * current throughout circuit constant

$V_{AB} = \frac{VR_{AB}}{R_{Tot}} = \frac{9(1000)}{1300}$

$\boxed{V_{AB} = 6.92\,V}$

(b) $I(t) = I_0 e^{-t/\tau}$

As time approaches Infinity, current approaches 0, so a long time after closing the switch $\boxed{V_{AB} \approx 0}$

(c) I'll define study state as the time it takes the charge to reach approximately 0.632 of the maximum charge $Q = C\mathcal{E}$.

$\tau = RC$
$= (1300)\left(\frac{10}{7} \times 10^{-6}\,F\right)$

$\boxed{\tau = 1.86 \times 10^{-3}\text{ seconds}}$