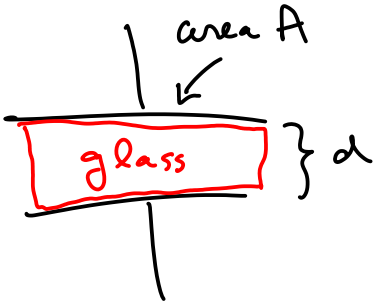
Lecture 33

Homework is due on Monday. Then the following Monday is exam 4.

If you score your exam within 1 standard deviation of the graders score then you 10 extra points on the exam.

Review: Calculation of the capacitance.



$$C = \frac{Q}{|\Delta V|} = \frac{\sigma A}{E d}$$

what σ?

This is the free charge since that is what we can control on a capacitor.

what E?

This is the electric field in the glass not in vacuum.

$$C = \frac{\sigma_f A}{\frac{\sigma_f}{\epsilon_0} d \frac{1}{1+\chi_e}} = \frac{\epsilon_0 A}{d}\underbrace{(1+\chi_e)}_{k} = C_0 k$$

Questions:

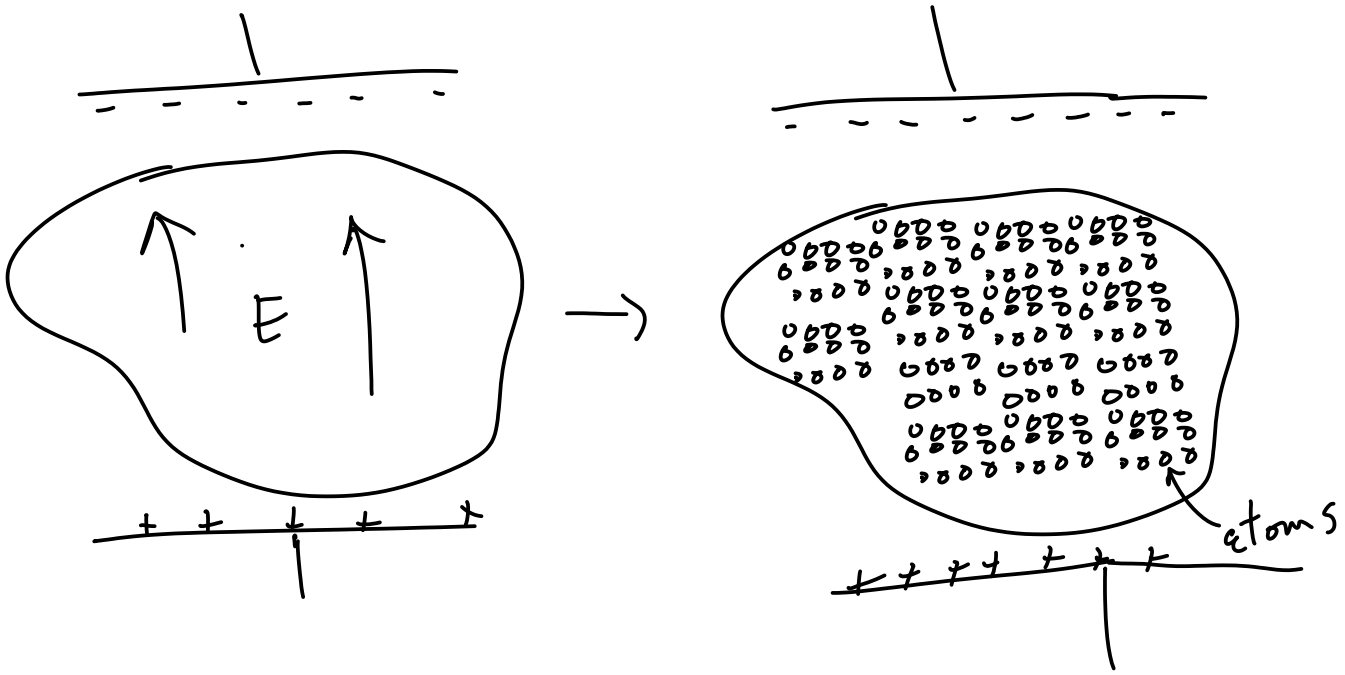
causal/creative: What is the cause of this increase in capacitance?

Analytic thinking (defn.): Capacitance is the amount of charge the battery delivers per volt.

The voltage across the cap is reduced since E is reduced and d is the same.
The capacitance is defined as the the charge per volt. Q doesn't change but V is reduced.

informational: How are caps used? Look up super capacitor on wikipedia. Check out the series cap model with leakage.

causal/creative: Nothing we have done uses the atomic nature of matter. How is that included? This is one main goals of this physics program is to be able to relate macroscopic phenomina to the microscopic world and vise versa.



Model?

Analytical thinking: start with defns and fundamental principles.

$\vec{P} = \epsilon_0 \chi_e \vec{E}_{tot}$ Dipole moment per unit volume. E_{tot} is the applied field plus the field from all the dipoles in the material.

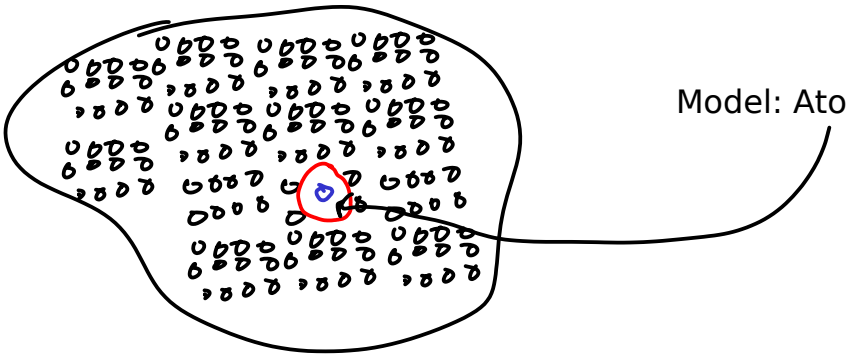
$\vec{p} = \alpha \vec{E}_{atom}$ Dipole moment per atom. E_{atom} is the field at the atom.

$\vec{P} = N \alpha \vec{E}_{atom}$ Atoms per volume times the dipole moment per atom.

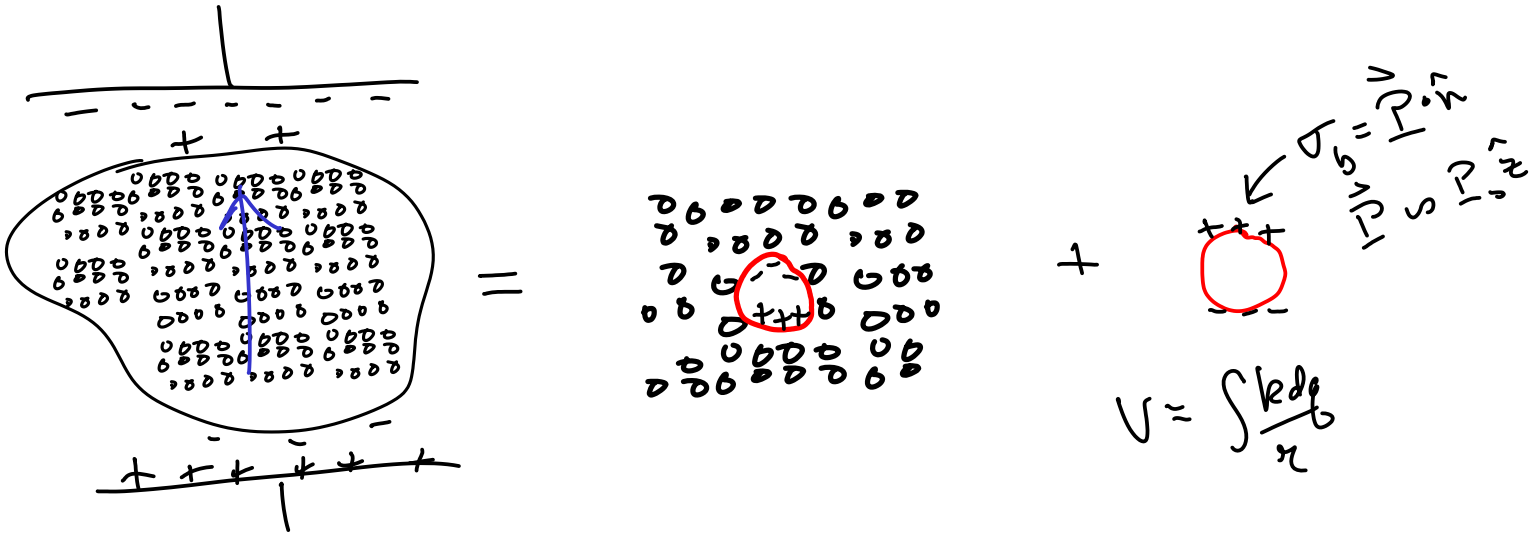
Questions:

causal/creative: Is E the field that an individual atom feels on average?

causal/creative: If I were an atom what E would I feel?



Model: Atom is in a spherical hole.



Homework problem 3. (a) Using the field of the hole to polarize an atom derive an expression for the dipole moment per unit volume that involves the atomic polarizability alpha. (b) Write an expression for the capacitance in terms of this atomic property.

$P = N \alpha E_{hole}$

α: polarizability of the atom (quantum calculation)

N: atoms/volume

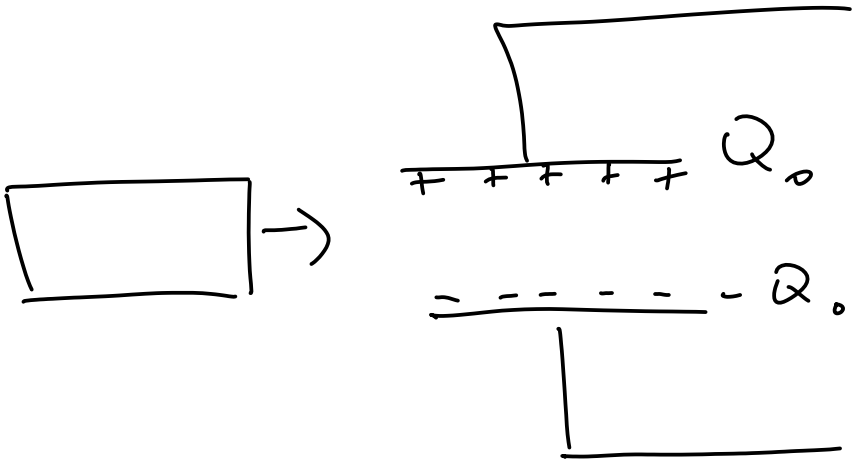
You will show that $$P = \frac{N\alpha}{1 - \frac{N\alpha}{3\epsilon_0}} \vec{E}$$

Questions:

incongruous: This is non-sense since P blows up as the denominator goes to zero.

As the polarizability gets larger the local field Ehole gets bigger. A larger local field polarizes the atoms more leading to positive feedback.

modifying: What happens if the cap is at constant voltage? First lets do constant charge.



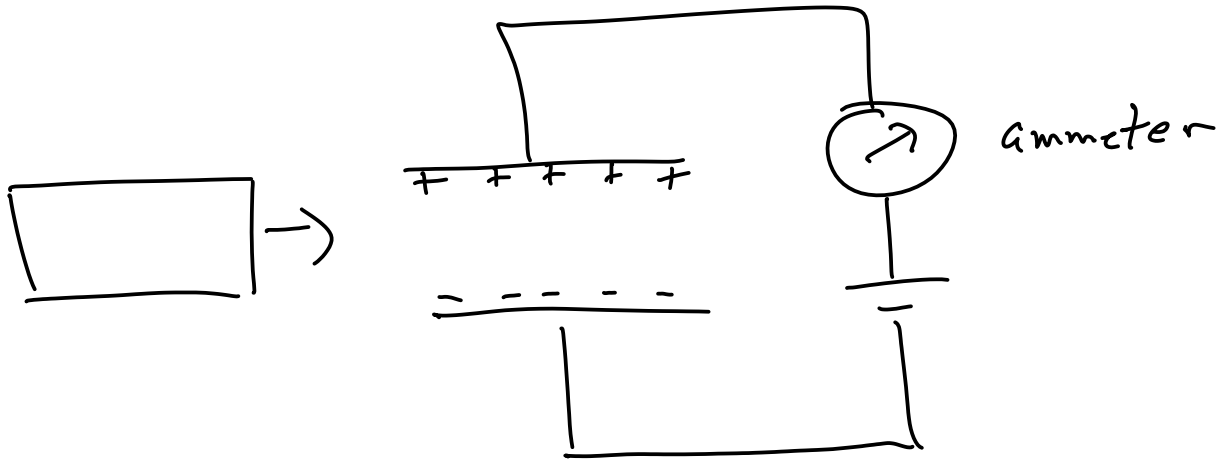
Charge stays the same but E decreases between the plates.

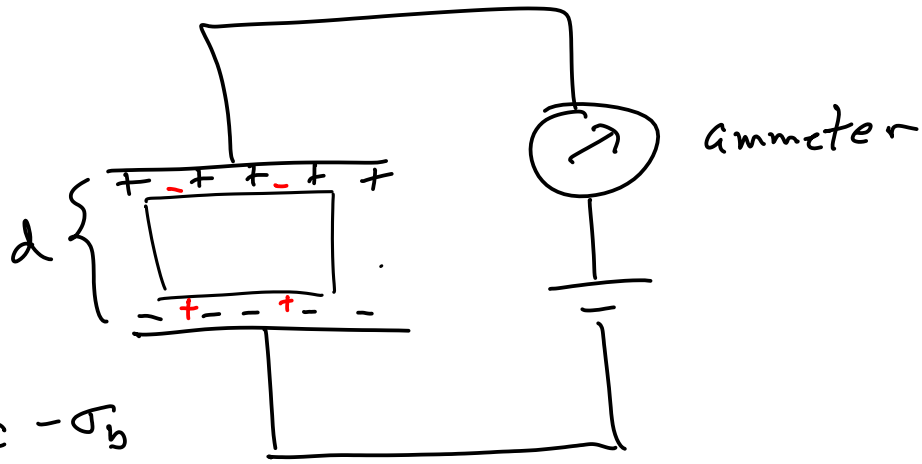
$$C_0 = \frac{Q_0}{V_0}; \quad V = \frac{Q_0}{C} \qquad \Delta V = \left.\frac{\partial V}{\partial C}\right|_Q dC + \left.\frac{\partial V}{\partial Q}\right|_{Q=0} dQ$$

Homework problem 4. Using these partial derivatives show where Vf is the voltage with the glass in the cap and Vi is that without the glass.

$$V_f = \frac{V_0}{1+\chi_e}$$

Back to constant voltage.





$$|\Delta V| = Ed$$

$$= \frac{\sigma}{\epsilon_0} = \frac{\sigma_f - \sigma_b}{\epsilon_0}$$

Battery has to pump more charge to the plates to compensate for the bound charge to generate the same E.

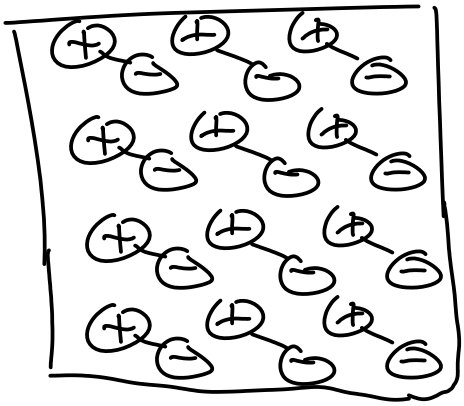
$$C = \frac{Q}{V} \quad \text{or} \quad Q = CV$$

$$\Delta Q = \left.\frac{\partial Q}{\partial C}\right|_V \delta C + \left.\frac{\partial Q}{\partial V}\right|_V \underbrace{\delta V}_{0}$$

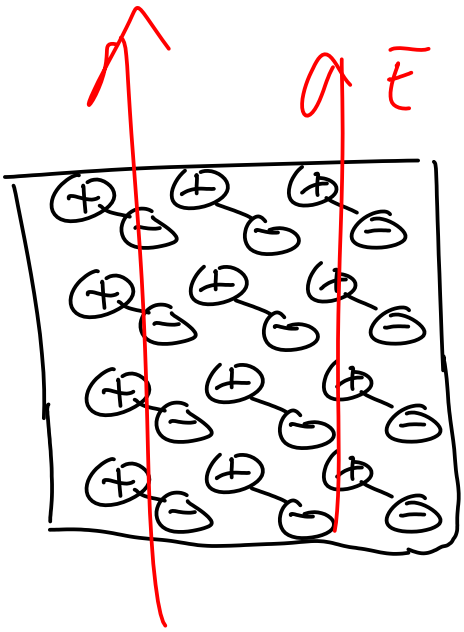
$$V\,(C_{glass} - C_0) = V(KC_0 - C_0) = \overbrace{VC_0}^{Q_0}\left(\frac{\epsilon}{\epsilon_0} - 1\right)$$

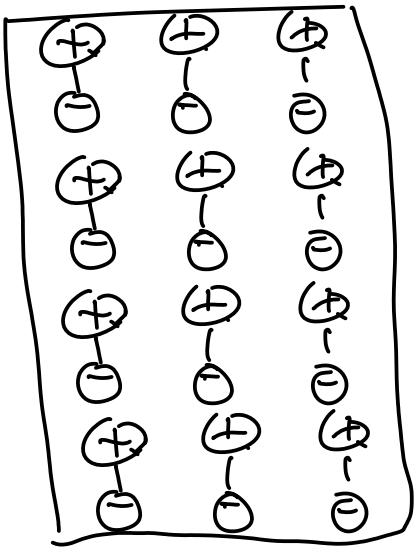
$$\Delta Q = Q_0\left(\frac{\epsilon_0(\chi_e + 1)}{\epsilon_0} - 1\right) = Q_0\chi_e = \underbrace{I}_{\text{ammeter}}\,\Delta t$$

piezo-electric crystal



Questions:



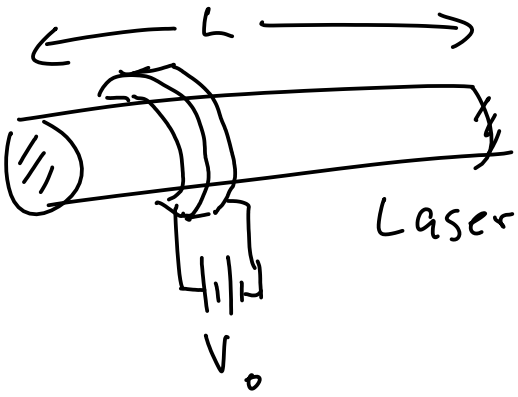


informational: How do you make a PZT?

Put the material in liquid state in a cap then cool it.

incongruous: Just apply a voltage and it can move an infinite mass. Does this violate energy cons?

To apply a voltage you are charging a capacitor with the PZT material inside. Calculate the energy stored and that is the maximum height to which you can raise and object of mass m (PE = mgh)

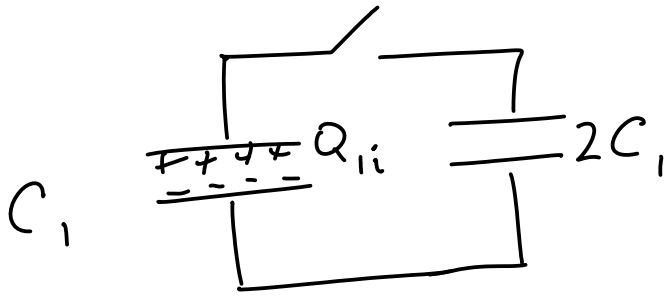


integer $\sim 10^6$

$V = \frac{nc}{2L}$

Elasticity of glass is the parameter associated with how easily it stretches when a force is applied.

Homework problem 5. Capacitor 1 is charged to voltage V0 before it is connected to capacitor 2. What is the final charge on the second capacitor when the switch is closed?



Knee-jerk thinking: Twice the charge goes to the second cap since its capcity is twice.

Analytical thinking: Conservation of charge must hold. Also the voltage on the upper and lower conductors is the same so the voltages across the two caps are the same.

Questions:

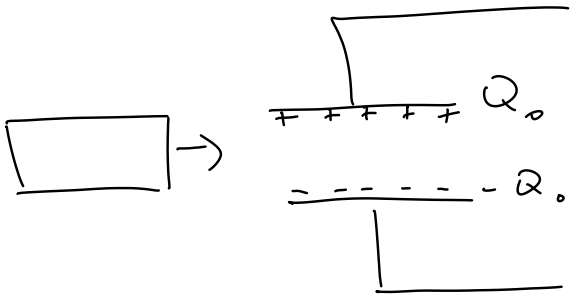
congruous: How do I calculate the effect of the inductance from the wire loop?

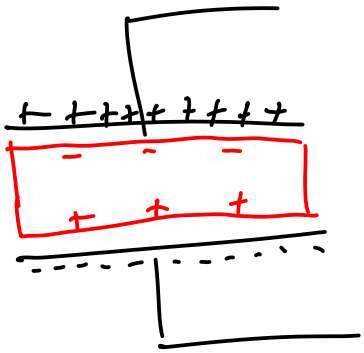
incongruous: Why doesn't the charge oscillate between the caps like energy in an LC circuit?

Field energy in matter

modifying: What simple example illustrate energy concepts in matter?

modifying: What is simpler, constant Q or V?





$$\text{Energy in cap} = \frac{1}{2}CV^2$$

In the math make what is constant explicit.

$$\text{Energy} = \frac{1}{2}\frac{Q^2}{C_o}$$

$$\text{Energy} = \frac{1}{2}\frac{Q^2}{KC_o}$$

Questions: