Lecture 34 continuing Ch. 6 Shadowitz

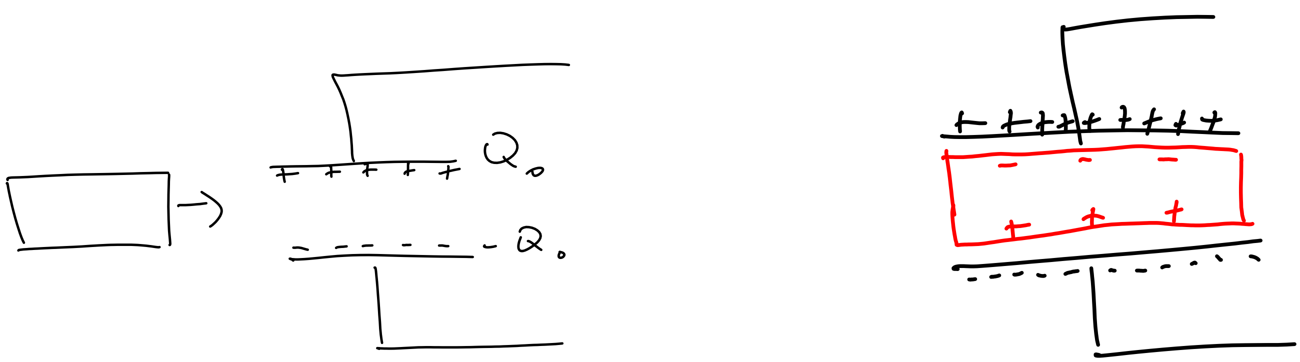
Homework is due on Monday. Should we have the exam 4 on Wednesday of the following week?

Field energy in matter

modifying: What simple example illustrates energy concepts in matter?

Lets try calculating energy conservation in a cap with and without a slab of glass.

modifying: In moving a slab into a capacitor, what is simpler, constant Q or V?



Energy in cap $= \frac{1}{2}C_0V^2 \longrightarrow \frac{1}{2}KC_0V^2$

Questions:

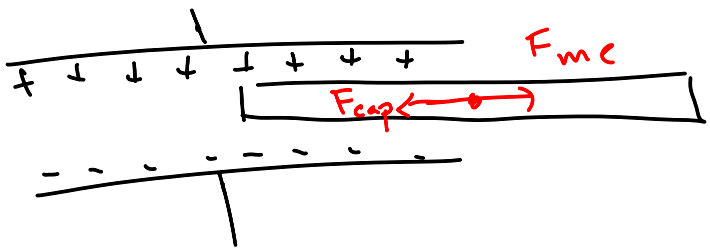
-incongruous: How can this eqn be right if the voltage is not constant?

-incongruous: How can energy be conserved?

Make the constant quantity explicit in the math.

$$\text{Energy}_{\text{before}} = \frac{1}{2}\frac{Q_{free}^2}{C_0} \quad > \quad \text{Energy}_{\text{after}} = \frac{1}{2}\frac{Q_{free}^2}{KC_0}$$

-incongruous: How can this be the total energy stored in the cap since is uses only the free charges in the defn of capacitance?



pull out at constant speed

$$W_{net} = \Delta KE$$

$$W_{non\text{-}cons} + W_{cons} = \Delta KE$$

$$W_{me} - \Delta PE = 0$$

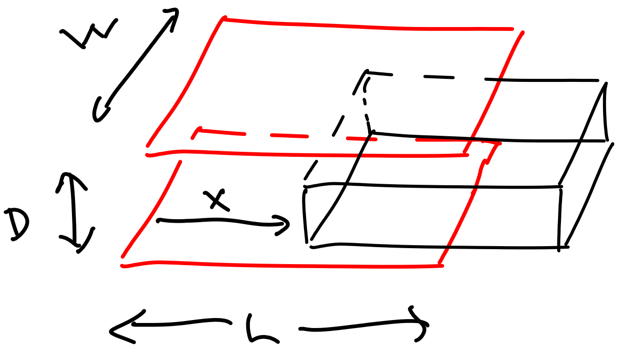
force of cap on slab

1-D $$dW_{me} = F_{me}\,dr = -F_{cap}\,dr$$

$$F_{cap} = \frac{-dW_{me}}{dr}$$

$$W_{me} = PE = \frac{1}{2}\frac{Q_{free}^2}{C}$$

Homework problem 6.) Derive an expression for the force on the slab using the geometry below.



Questions:

informational: What's the answer?

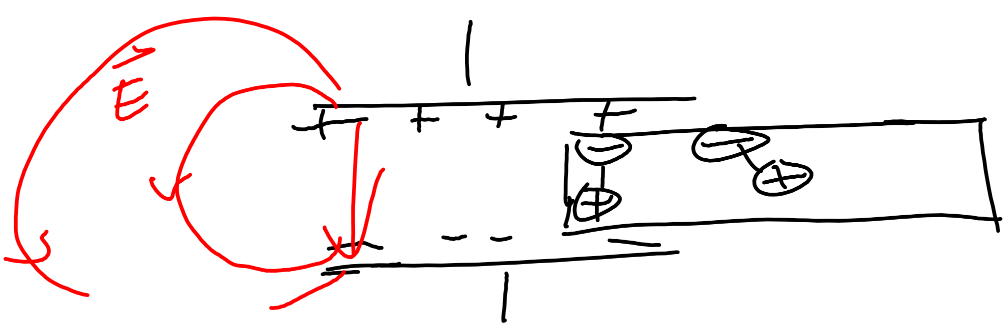
informational: What direction of the force do I expect?

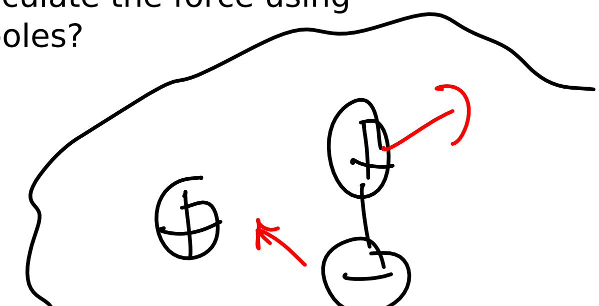
congruous: How do I calculate the dependence of the capacitance on position?

modifying: What is different if this is done at constant voltage?

causal/creative: Why does the slab move in? This model gives little insight.

congruous: I understand forces on dipoles. How do I calculate the force using a model in which the glass consists of dipoles?

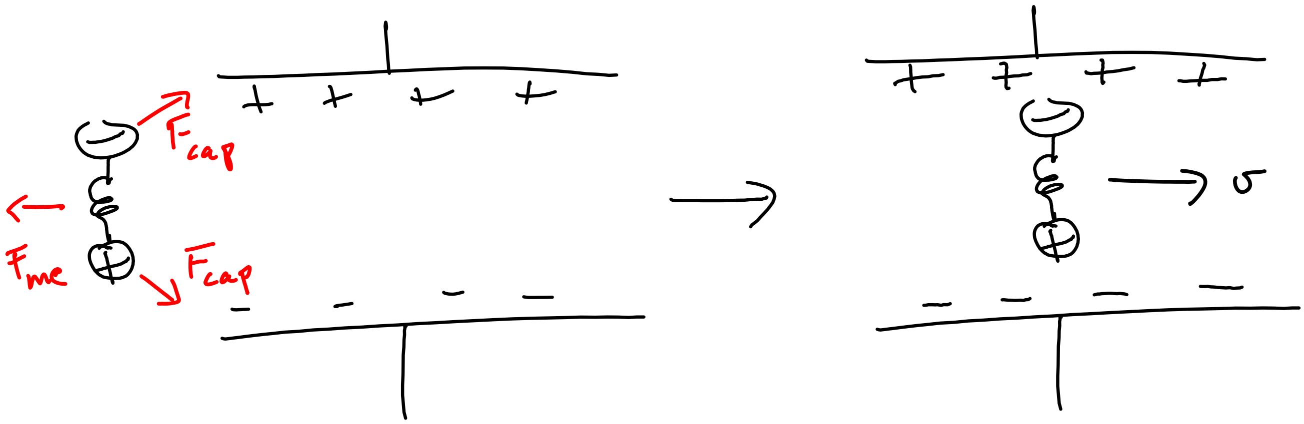




Force on a dipole in a non-uniform E

The fringing field act on the induced dipoles to create the force. However, using energy method we don't have to calculate these forces.

causal/creative: This still seems too complicated to understand what's going on.
How can we simplify this even more to understand
why the capacitor stores less energy with a dielectric inserted?

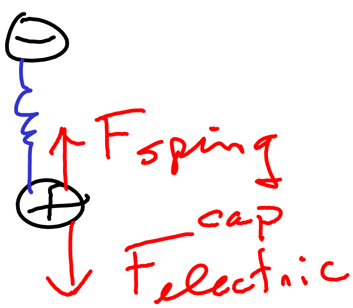


To bring the dipole into the cap

$$W_{net} = \Delta KE = 0$$

$$\Delta W_{me} + \Delta W_{spring} + \Delta W_{field} = 0$$

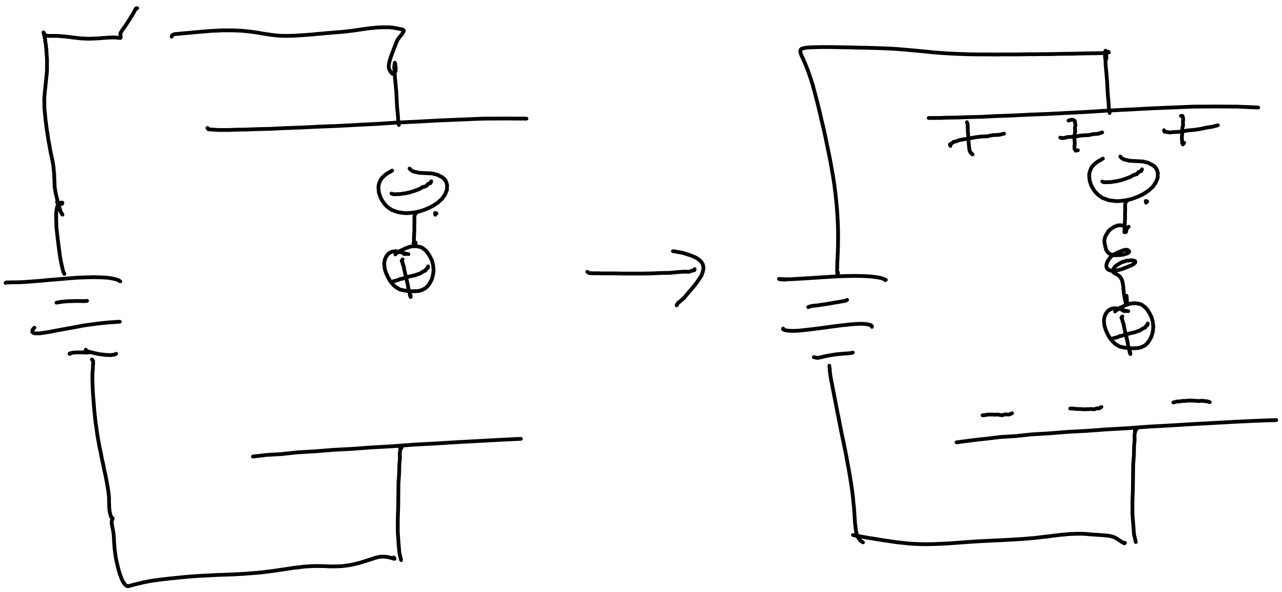
$$\Delta W_{me} + \Delta W_{spring} = \Delta PE_{field}$$



The energy in the field must have decreased by an amount equal to the work done by me and that in stretching the spring.

$$\text{Energy}^{cap, before} = \frac{1}{2}\frac{Q_{free}^2}{C_0} > \text{Energy}^{cap, after} = \frac{1}{2}\frac{Q_{free}^2}{KC_0}$$

modifying: What happens if we just turn on the voltage without moving the diplole?



$$W_{net} = \Delta KE = 0$$

$$W_{battery} + W_{field} + W_{spring} = 0$$

The battery has to do work to stretch the spring and generate the field by assembling like charges on each plate of the capacitor. When you disconnect the battery there is this energy stored in the capacitor.

informational: Is the energy I can get out of a charged cap the field AND spring energy?

modifying: Is there any such extra energy stored in a permanent dipole?

more

We are done with the physics but not with reformulating the math.

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0} \qquad -\vec{\nabla} \cdot \vec{P} = \rho_{bound}$$

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho_{free}}{\epsilon_0} + \frac{\rho_{bound}}{\epsilon_0} = \frac{\rho_f}{\epsilon_0} - \frac{\vec{\nabla} \cdot \vec{P}}{\epsilon_0}$$

$$\epsilon_0 \vec{\nabla} \cdot \vec{E} + \vec{\nabla} \cdot \vec{P} = \rho_f$$

$$\oint \vec{D} \cdot d\vec{a} = Q_{free\ enclosed}$$

$$\vec{\nabla} \cdot \underbrace{(\epsilon_0 \vec{E} + \vec{P})}_{\shortparallel} = \rho_f$$

$$\int \vec{\nabla} \cdot \vec{D} \, d\tau = \int \rho_f \, d\tau$$

$$\vec{\nabla} \cdot \vec{D} = \rho_f \qquad \text{Gauss's Law}$$

$$D = \epsilon_0 \vec{E} + \vec{P}$$

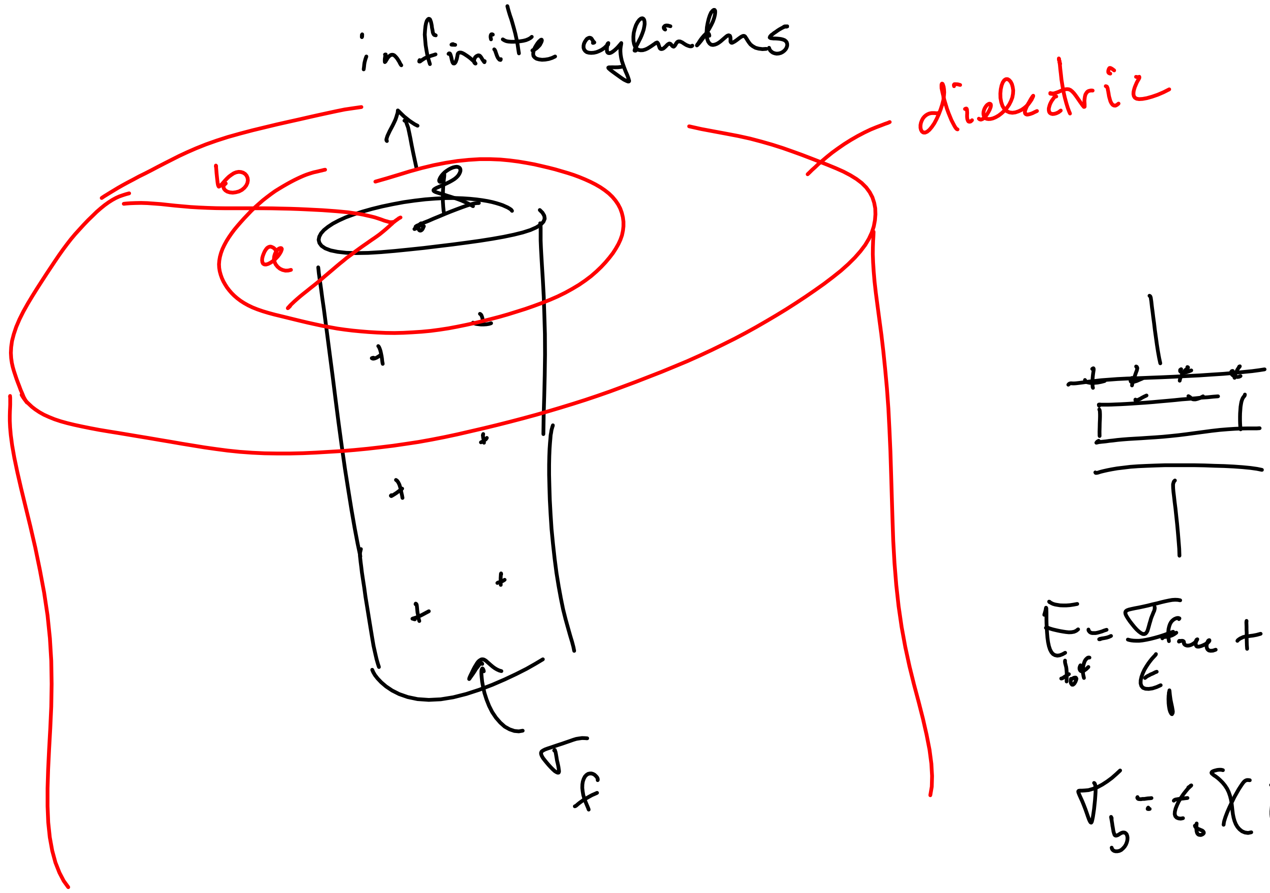
linear

$$\vec{D} = \epsilon_0 \vec{E} + \epsilon_0 \chi_e \vec{E}$$

$$\vec{D} = \underbrace{\epsilon_0 (1 + \chi_e)}_{\epsilon} \vec{E}$$

$$\vec{D} = \epsilon \vec{E} \qquad \text{linear materials}$$

Homework problem 7: Use the integral form of Gauss's law to determine the electric field in the dielectric shown below. (b) find the surface bound charge on both surface of the linear material of suceptibility χ_e.



$$E_{tot} = \frac{\sigma_{free}}{\epsilon_1} + \frac{\sigma_b}{\epsilon_0}$$

$$\sigma_b = \epsilon_0 \chi E_{tot}$$

Questions:

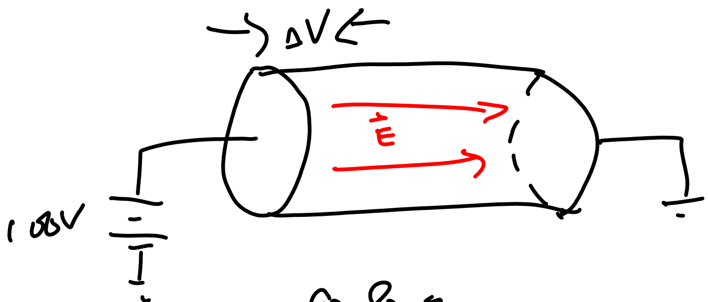
congruous: What is the curl of D since that is needed to specify the vector function?

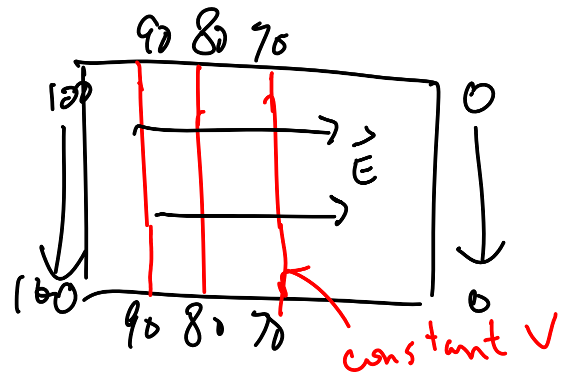
congruous: How do I calculate D in a simple situation?

informational: Why mess with my mind in defining new stuff?

Look up permittivity on wikipedia.

Look up comsol.com/multiphysics





$$K \nabla^2 T(x,y,z,t) = C_v \frac{\partial T(x,y,z,t)}{\partial t} - S(x,y,z,t)$$

Thermal conductivity

heat capacity

thermal energy per volume related to current density

Equation for thermal expansion

$$\Delta V = V_0 \alpha \Delta T$$

change in volume

initial volume

thermal expansion coefficient

change in temperature

Glass will break if it expands or contracts too non-uniformly.