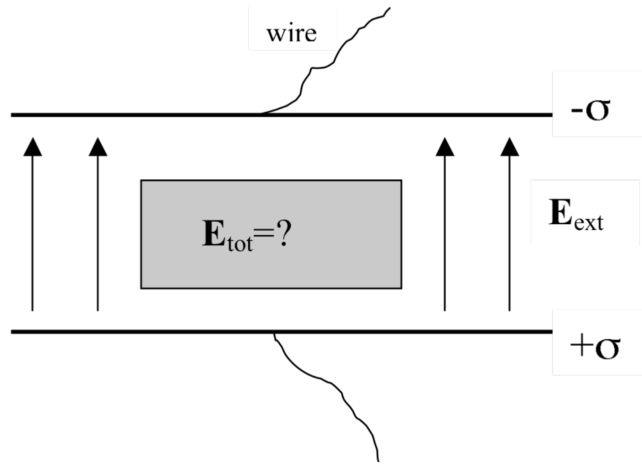
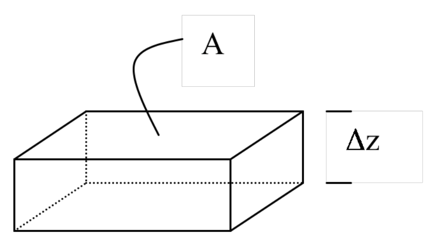
Part 1 – Polarization and Bound Charge

A slab of plastic is placed within a charged capacitor. Before inserting the plastic, there is a uniform electric field inside the capacitor, $\mathbf{E}_{ext}$. We will explore the properties of a dielectric to eventually find the electric field inside the plastic.



i. You can think about the microscopic picture inside the plastic as looking like many negative charges "-q", each bound to a fixed positive core "+q", with a spring constant k. Draw a “zoomed-in” sketch of the top few rows of atoms inside the plastic (when the plastic is inside the capacitor).

ii. When the plastic is inside the capacitor, the “spring” stretches a distance Δz. If there are N charge carriers per unit volume, what is the total charge enclosed in a volume of height Δz, and area A? Why should you only enclose the top row of charges?



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iii. Using your expression for the charge enclosed, what is the surface-charge density? This is called the bound-charge density, σ_B. Once you have σ_B, look for ways to simplify your expression as much as possible (using identities we've recently covered in class, **p** and **P**).

iv. Check to see if your expression for σ_B is consistent with the formula: $\sigma_B = \vec{P} \bullet \hat{n}$

v. What is σ_B on the *bottom* surface of the plastic slab? Is this consistent with the formula: $\sigma_B = \vec{P} \bullet \hat{n}$?

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Part 2 – Electric Fields in Dielectric Materials (or Insulators)

i. What is the magnitude of the induced electric field, $\mathbf{E}_{ind}$, inside the plastic slab?

Express it in three ways:

1. in terms of σ_B, the bound charge
2. in terms of P, the polarization
3. in terms of Δz, the distance the atom "stretches"

In each case, are any other "givens" (i.e. $\mathbf{E}_{ext}$, N, ε_0, q) needed?

ii. What is the magnitude of the total electric field inside the plastic slab, $|\mathbf{E}_{tot}|$, in terms of the magnitude of the induced field, $|\mathbf{E}_{ind}|$, and the magnitude of the external field of the capacitor, $|\mathbf{E}_{ext}|$?

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iii. Given a spring constant k, find Δz.

iv. Now you have everything you need to write down $\mathbf{E}_{tot}$, the electric field inside the plastic. Make sure you express it using only the "givens" ($\mathbf{E}_{ext}$, N, ε_0, q, k).

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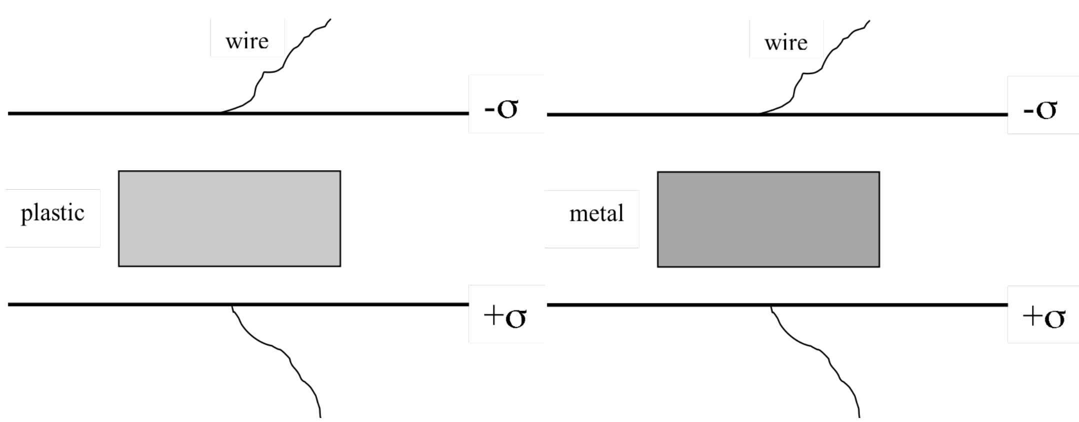
Part 3 – Making Sense of the Answer

It's a good idea to always use a limiting case to check if your answer makes sense.

i. What physical situation would you model as an "ultra" weak spring? What is k in that situation? What is $\mathbf{E}_{tot}$? Does that make sense?

ii. Griffiths' equation 4.21 states: $\vec{D} = \varepsilon_o \vec{E} + \vec{P}$. Here, we've had three **E**'s. Which one does Griffiths mean in this equation? Is this consistent with saying that "**D** arises from free charge"?

iii. Sketch the electric field strength and any bound charges everywhere inside the capacitor plates for: 1. the plastic slab; 2. same size chunk of metal



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iv. Which slab (plastic or metal) “feels” a bigger force from the external field, $\mathbf{E}_{ext}$?

Demo: Taking your previous answer into consideration, will an oil stream (dielectric) or a water stream (conductor) feel a bigger force from a nearby charged object?

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