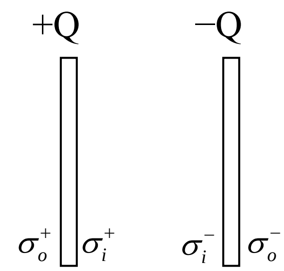
Discussion Question 5C
P212, Week 5
Designing a Capacitor

A **capacitor** is nothing more than two conducting objects (called ***terminals***) that are separated by an insulating medium. If we attach a battery to such an object, a charge $+Q$ will accumulate on one of the plates, and an equal and opposite charge $-Q$ will accumulate on the other. That's the purpose of a capacitor: it's a device to store charge. Knowing that helps us remember the formula for capacitance, $C = Q/\Delta V$ $\rightarrow$ a "***big***" capacitor (large C) can store a *lot* of charge with *little* voltage. Let's build one!

Two large circular plates made of metal have area $A = 2$ m^2. They are arranged parallel to each other and are separated by a distance d = 1.5 cm. The gap between the plates is filled with air. Together, the plates form a **parallel-plate capacitor**.



(a) Where do the charges go?

1. Place a charge $+Q$ on one terminal and a charge $-Q$ on the other. Write down the surface charge densities, σ_i and σ_o, for the inner and outer surfaces of each plate.

   $\sigma_o^+ = 0$, $\sigma_i^+ = Q/A$, $\sigma_i^- = -Q/A$, $\sigma_o^- = 0$

2. What is the electric field to the left or right of the two plates?
   E = 0

3. What is the electric field between the two plates?

$$E = 2\frac{\sigma}{2\varepsilon_0} = \frac{Q/A}{\varepsilon_0}$$

(b) What is the capacitance of this system?

1. What is the potential difference ΔV between the plates?
   $\Delta V = Ed$

2. What is the definition of capacitance? Use it, and your answer to (a) part 3, to calculate C for this device.

$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{d} = 1.18\ nF$$

(c) Is the capacitance a property of the geometry and the material between the plates, or does it depend on the voltage and charge applied to the capacitor?

Think about it this way: if you changed the voltage applied to your device, would C change? If you doubled the distance between the plates, would C change?

C determined via Q/ΔV but only depends on the geometry.

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(d) Design a parallel-plate capacitor with capacitance 100 pF (pF = "picoFarad" = 10^{-12} Farads).

1. What features does the capacitance depend on?

2. Using the parallel-plate formula you determined in (a), and select the dimensions of your device so that you meet the 100 pF design specification.

Answers will vary. It depends on area, dielectric constant and plate separation

(e) The initial capacitor (A = 2 m^2, d = 1.5 cm) has been built, but your troublesome client now insists that the capacitance be increased by a factor of 2. Without changing the dimensions of the capacitor, what can be done?

Insert a dielectric material with $\kappa = 2$

(f) Consider your initial capacitor again (A = 2 m^2, d = 1.5 cm, air between the plates). If the plates are moved to a new separation of D = 5 cm, do the following magnitudes increase, decrease, or stay the same?

- Charge density on each plate stays the same

- Electric field between the plates stays the same

- Potential difference between the plates increases

- Capacitance decreases

(g) For your initial capacitor (A = 2 m^2, d = 1.5 cm), suppose the plates are first discharged and then connected to a battery having voltage V_0. If the plates <u>remain connected to the battery</u> but are moved to a new separation of D = 5 cm, do the following magnitudes increase, decrease, or stay the same?

- Charge density on each plate decreases

- Electric field between the plates decreases

- Potential difference between the plates stays the same

- Capacitance decreases