Purdue University Department of Physics

Physics 24100

Electricity & Optics

Lecture 9 – Chapter 24 sec. 3-5

Fall 2012 Semester

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Thursday’s Clicker Question

- To double the capacitance of a parallel plate capacitor, you should:

(a) Double the area of the plates
(b) Half the distance between the plates
(c) Both (a) and (b)
(d) Either (a) or (b)

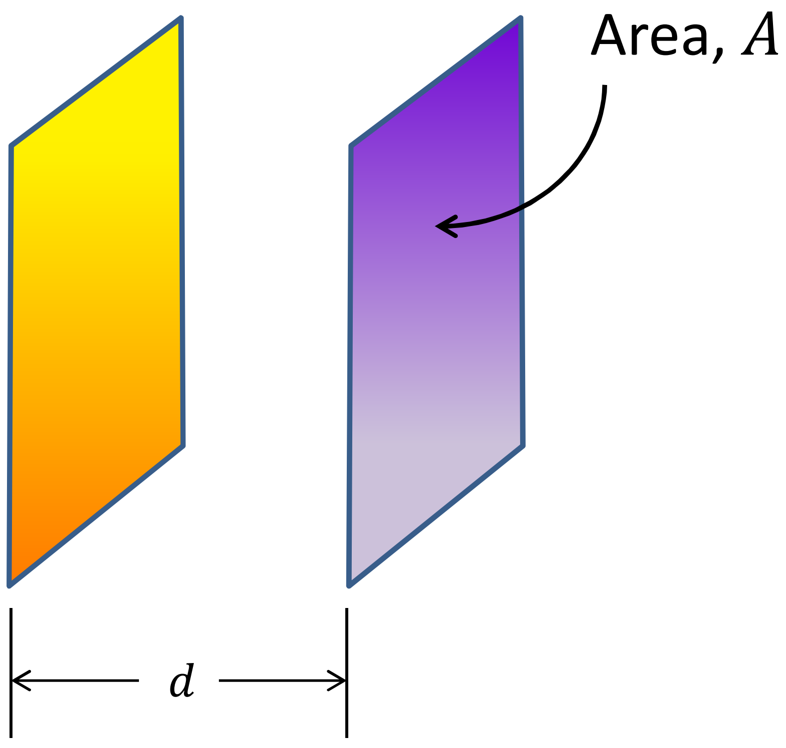
Thursday's Clicker Question

- To double the capacitance of a parallel plate capacitor, you could *either* double the area *or* half the distance:

$$C = \frac{\epsilon_0 A}{d}$$

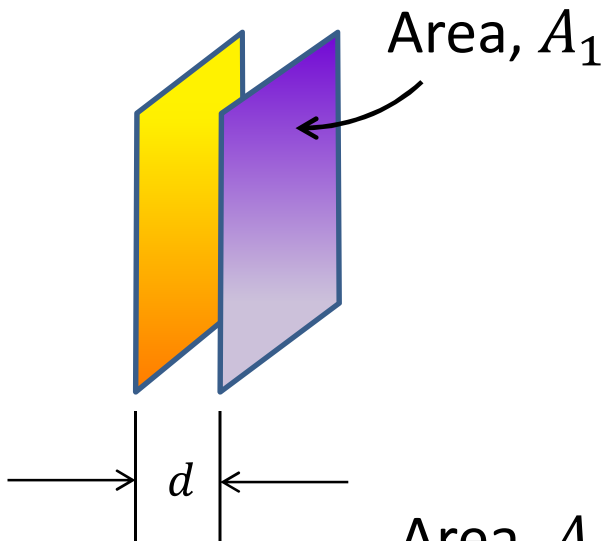
- If you did both you would *quadruple* the capacitance.

Parallel Plate Capacitor

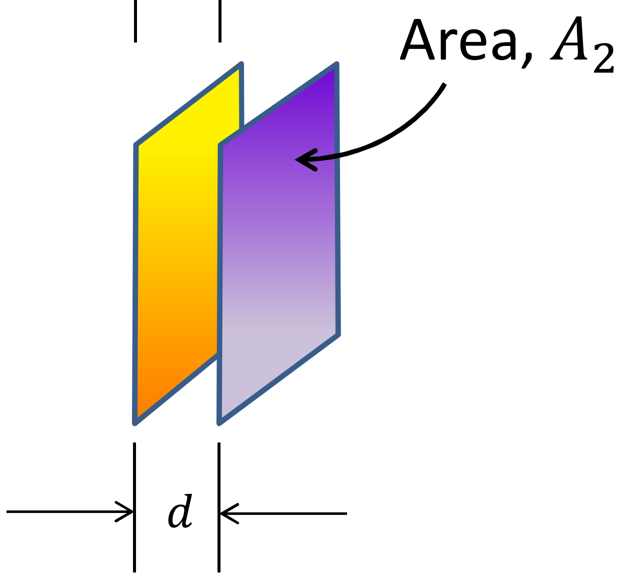


$$C = \frac{\epsilon_0 A}{d}$$

Two Parallel Plate Capacitors

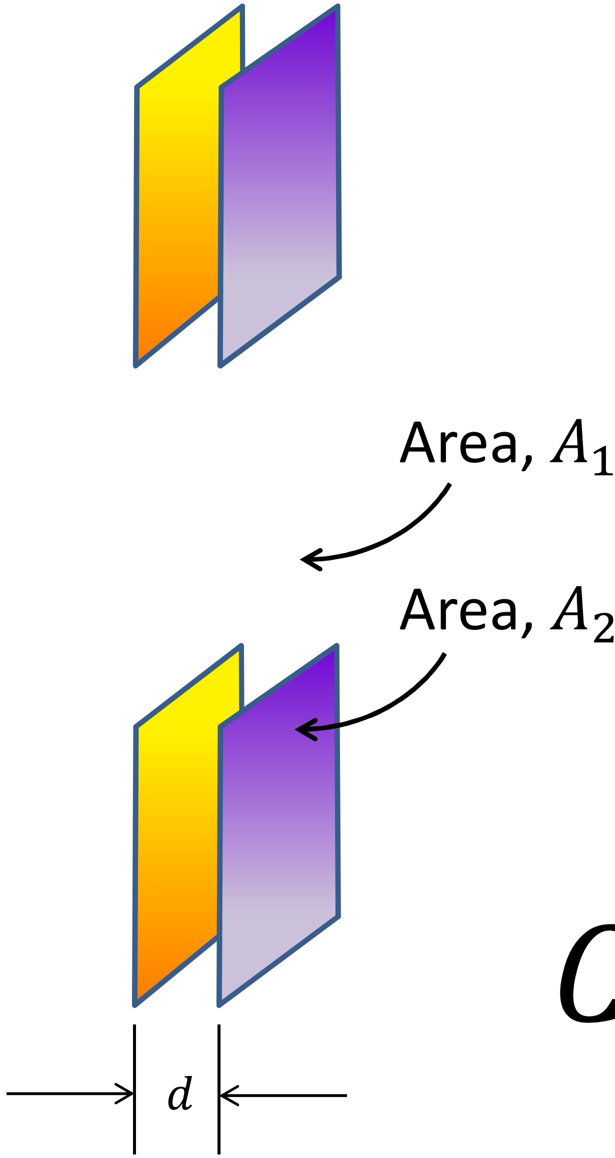


$$C_1 = \frac{\epsilon_0 A_1}{d}$$



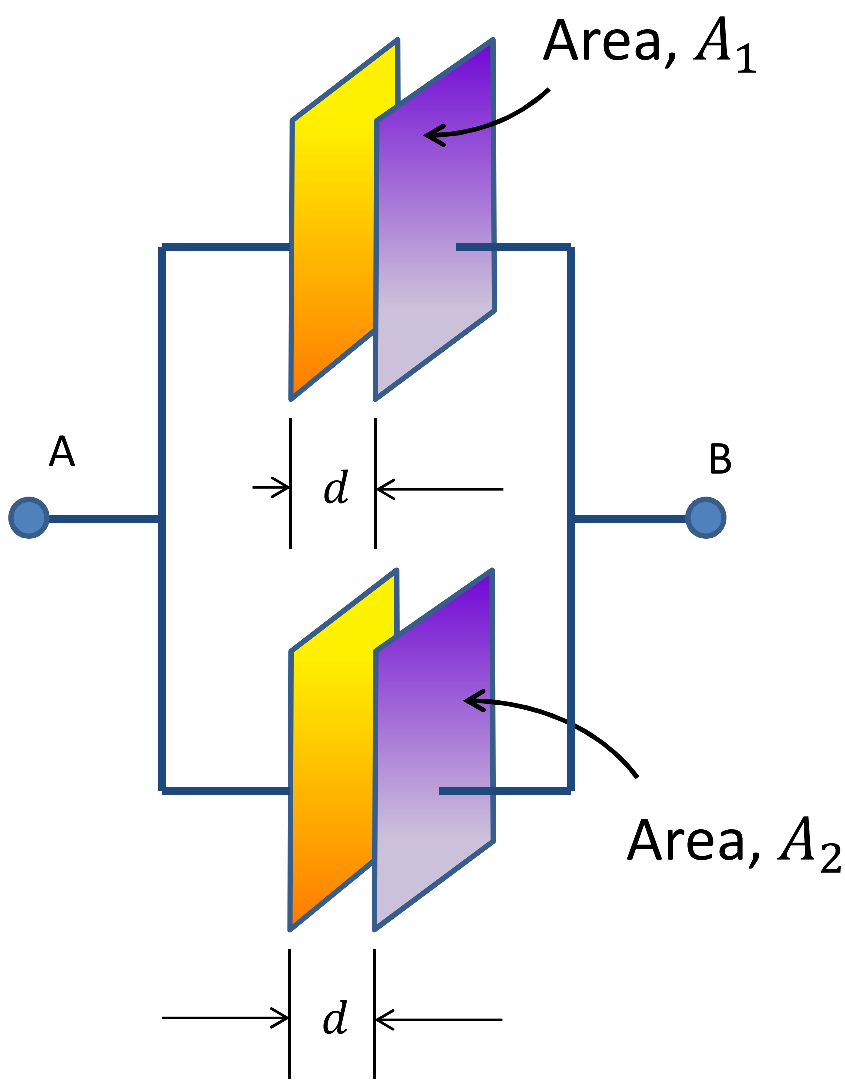
$$C_2 = \frac{\epsilon_0 A_2}{d}$$

One Big Parallel Plate Capacitor



$$C = \frac{\epsilon_0 (A_1 + A_2)}{d}$$

Two Parallel Plate Capacitors



- Remember: *conductors in electrical contact have the same electric potential.*
- We could measure the potential difference between points A and B if they were connected to the plates with wires.

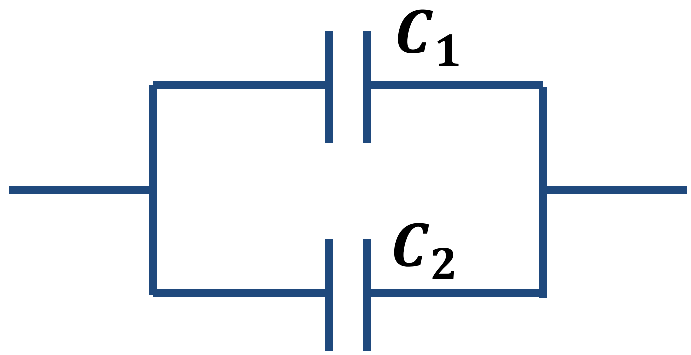
$$Q = C\,V$$

$$C = \frac{\epsilon_0(A_1 + A_2)}{d}$$

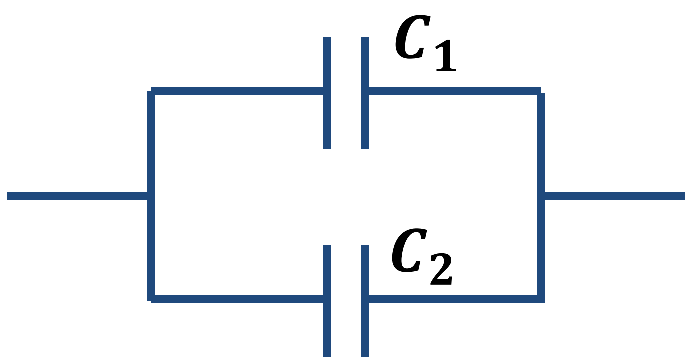
Capacitors In Parallel

- Symbol for a capacitor:

- Capacitors in parallel:



- Equivalent capacitance:



$$C = C_1 + C_2$$

Capacitors in Parallel

- Consider two capacitors, C_1 and C_2, with the same potential difference, V, across them.
- The charge on each one is

$$Q_1 = C_1 V$$
$$Q_2 = C_2 V$$

- If they are connected in parallel then the potential difference doesn't change but now we can write:

$$Q = Q_1 + Q_2 = (C_1 + C_2)V = C\ V$$

where

$$\boldsymbol{C = C_1 + C_2}$$

Capacitors in Series

- Consider two capacitors, C, each with potential difference, V, and charge $Q = CV$:

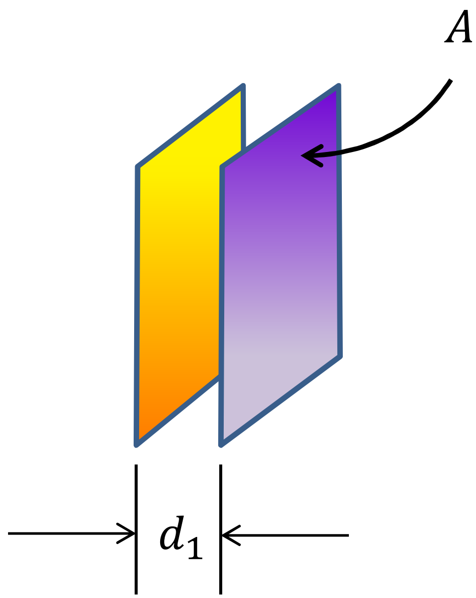
- If they are brought into electrical contact the potential difference is $2V$ but the charge is still Q.
- The effective capacitance is C' where

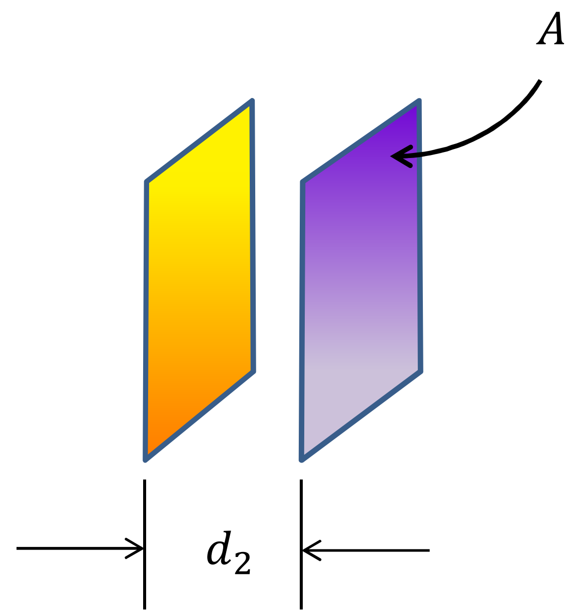
$$C' = \frac{Q}{2V} = \frac{C}{2}$$

- *Equivalent series capacitance is reduced.*

Capacitors in Series

- Consider two parallel plate capacitors:

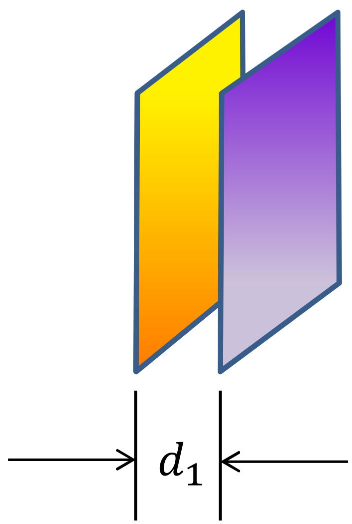


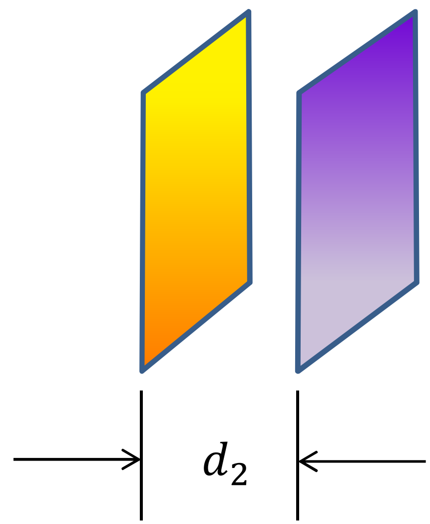


$$C_1 = \frac{\epsilon_0 A}{d_1} \qquad C_2 = \frac{\epsilon_0 A}{d_2}$$

Capacitors in Series

- Consider two parallel plate capacitors:





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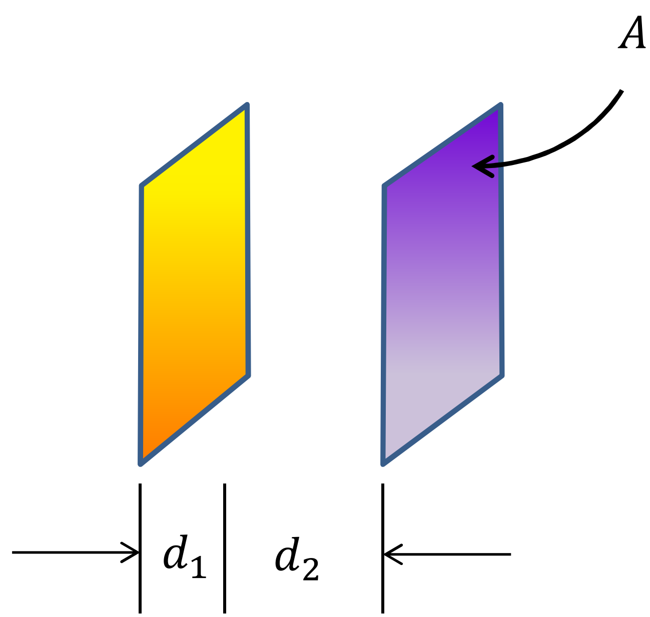
Capacitors in Series

- Consider two parallel plate capacitors:



$$C = \frac{\epsilon_0 A}{d_1 + d_2}$$

Capacitance in Series

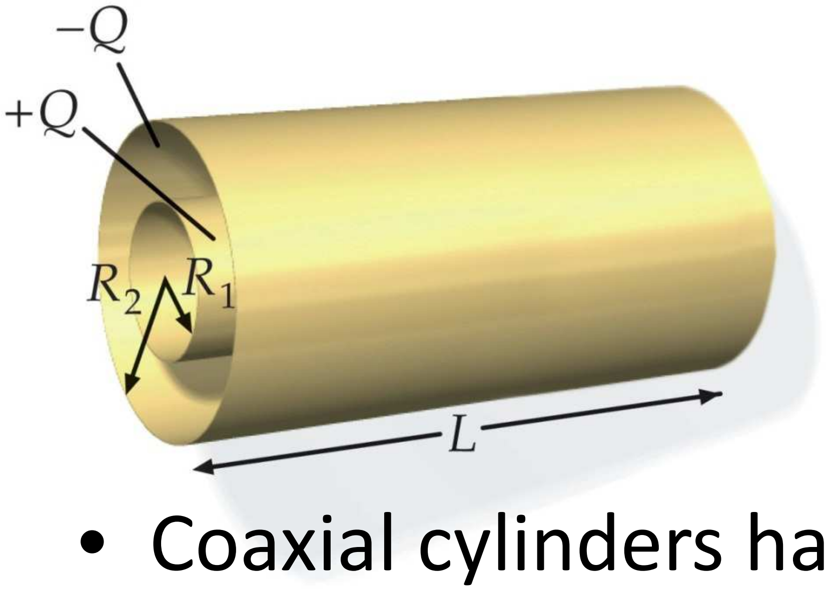
$$C = \frac{\epsilon_0 A}{d_1 + d_2}$$

$$\frac{1}{C} = \frac{d_1 + d_2}{\epsilon_0 A} = \frac{1}{C_1} + \frac{1}{C_2}$$

- Equivalent series capacitance:

$$C = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1}$$

Example: Equivalent Capacitance



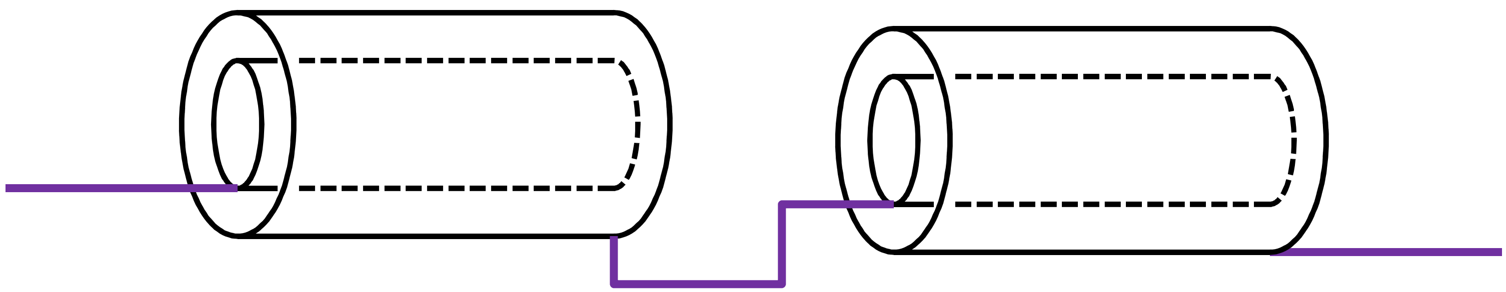
- Coaxial cylinders have capacitance

$$C = \frac{2\pi\epsilon_0 L}{\log(R_2/R_1)}$$

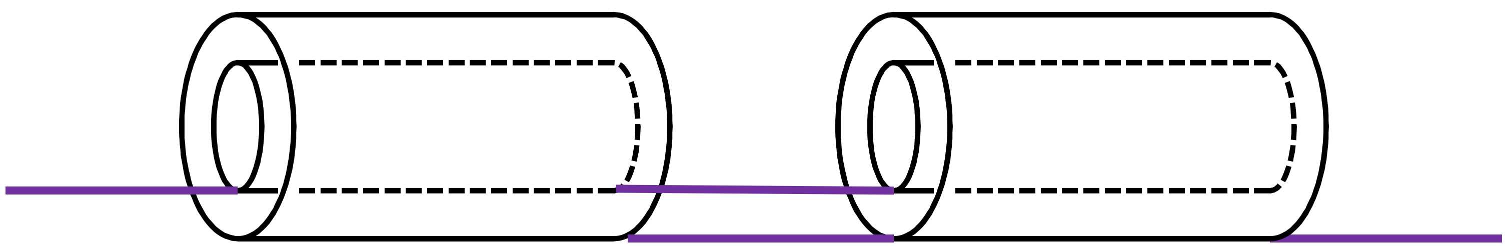
- Suppose three identical coaxial cylinders were connected together in a particular way…
- What would be the equivalent capacitance?

Example: Equivalent Capacitance

- There are two ways to connect them:
  - In series (outside to inside):

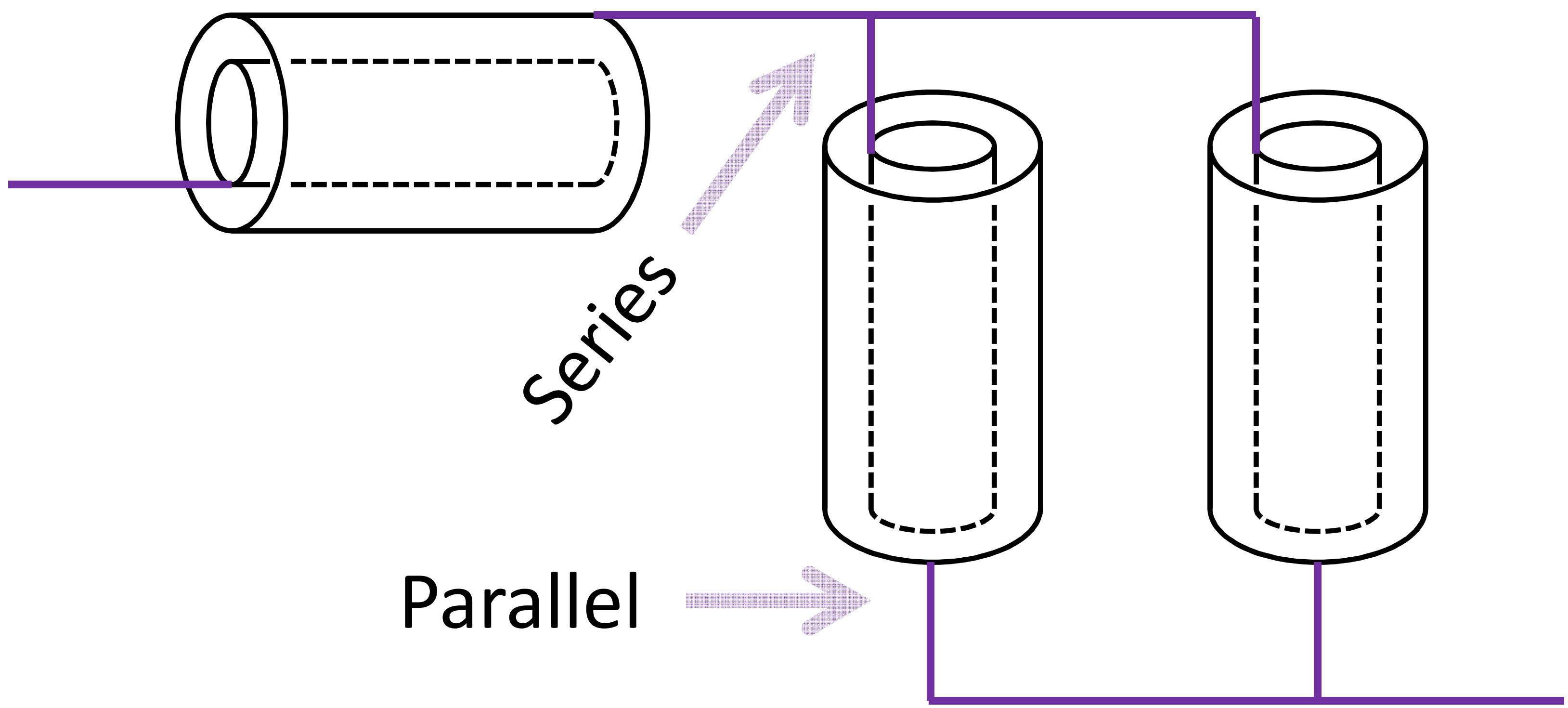


  - In parallel (inside to inside, outside to outside):



Example: Equivalent Capacitance

- What is the equivalent capacitance when connected in the following way?



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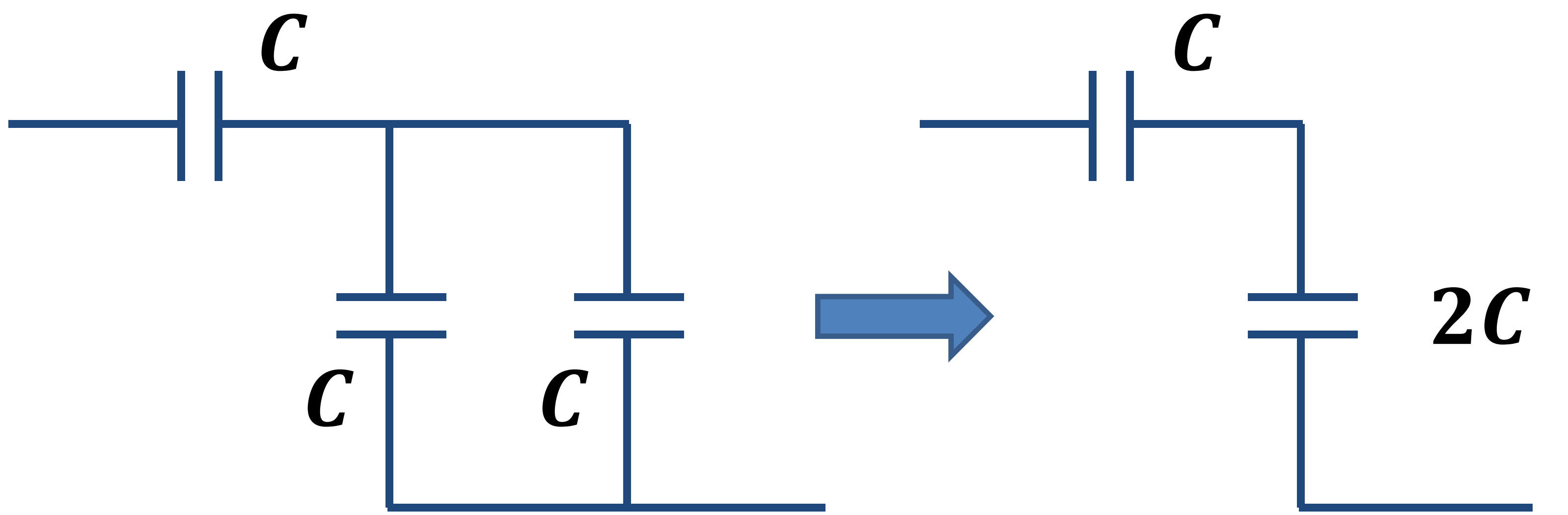
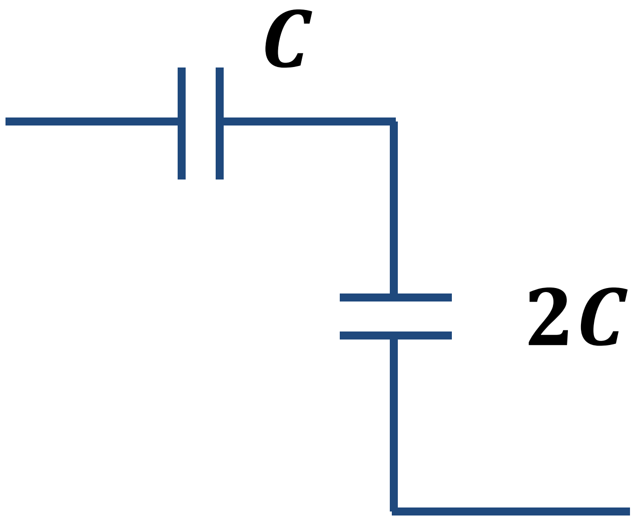


Combine capacitors in parallel: $C = C_1 + C_2$

Example: Equivalent Capacitance

- What is the equivalent capacitance when connected in the following way?

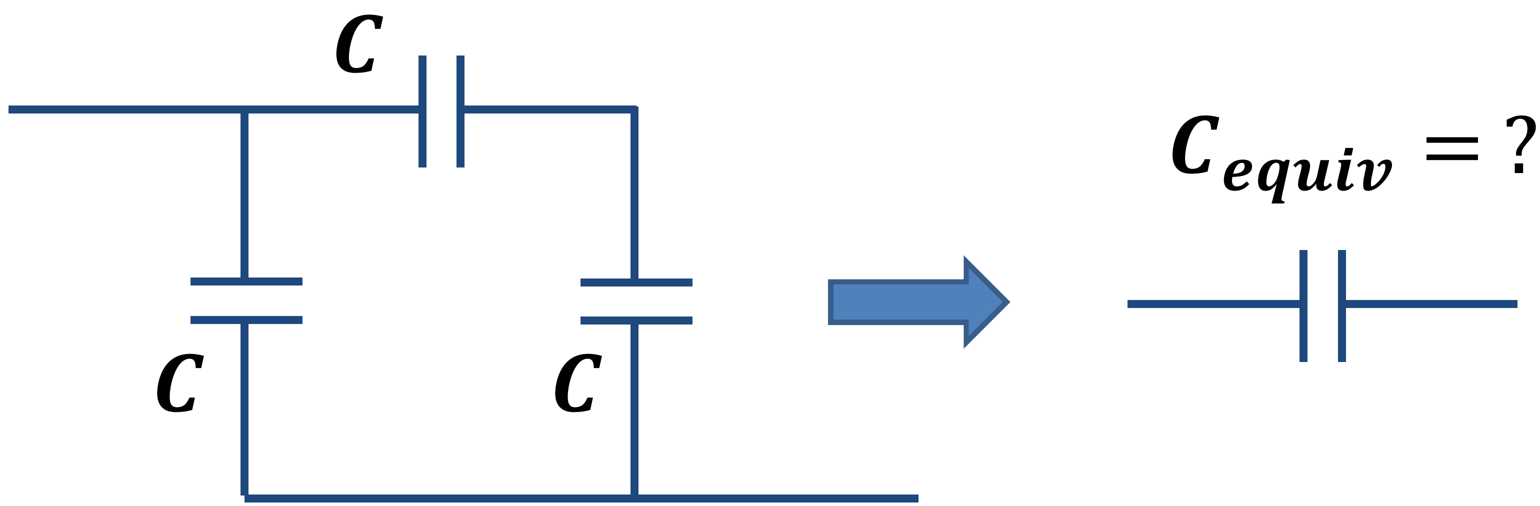


$$\left(\frac{1}{C}+\frac{1}{2C}\right)^{-1}=\frac{2}{3}C$$

Combine capacitors in series: $C=\left(\frac{1}{C_1}+\frac{1}{C_2}\right)^{-1}$

Question

- What is the value of the equivalent capacitance:



(a) $C_{equiv} = \frac{2}{3}C$

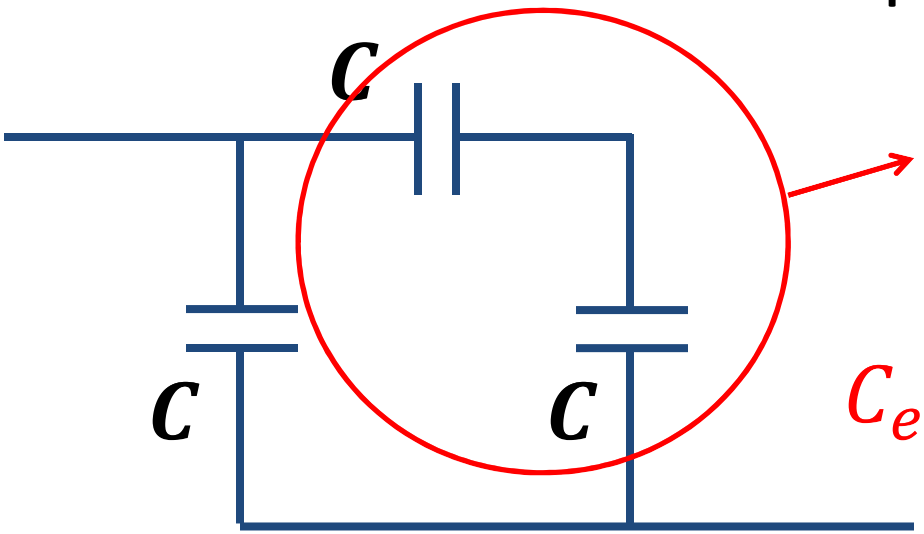
(b) $C_{equiv} = \frac{3}{2}C$

(c) $C_{equiv} = 3C$

(d) $C_{equiv} = \frac{1}{3}C$

Question

- What is the value of the equivalent capacitance:



$$C' = \left(\frac{1}{C} + \frac{1}{C}\right)^{-1} = \frac{C}{2}$$

$$C_{equiv} = C + \frac{C}{2} = \frac{3}{2}C$$

(a) $C_{equiv} = \frac{2}{3}C$

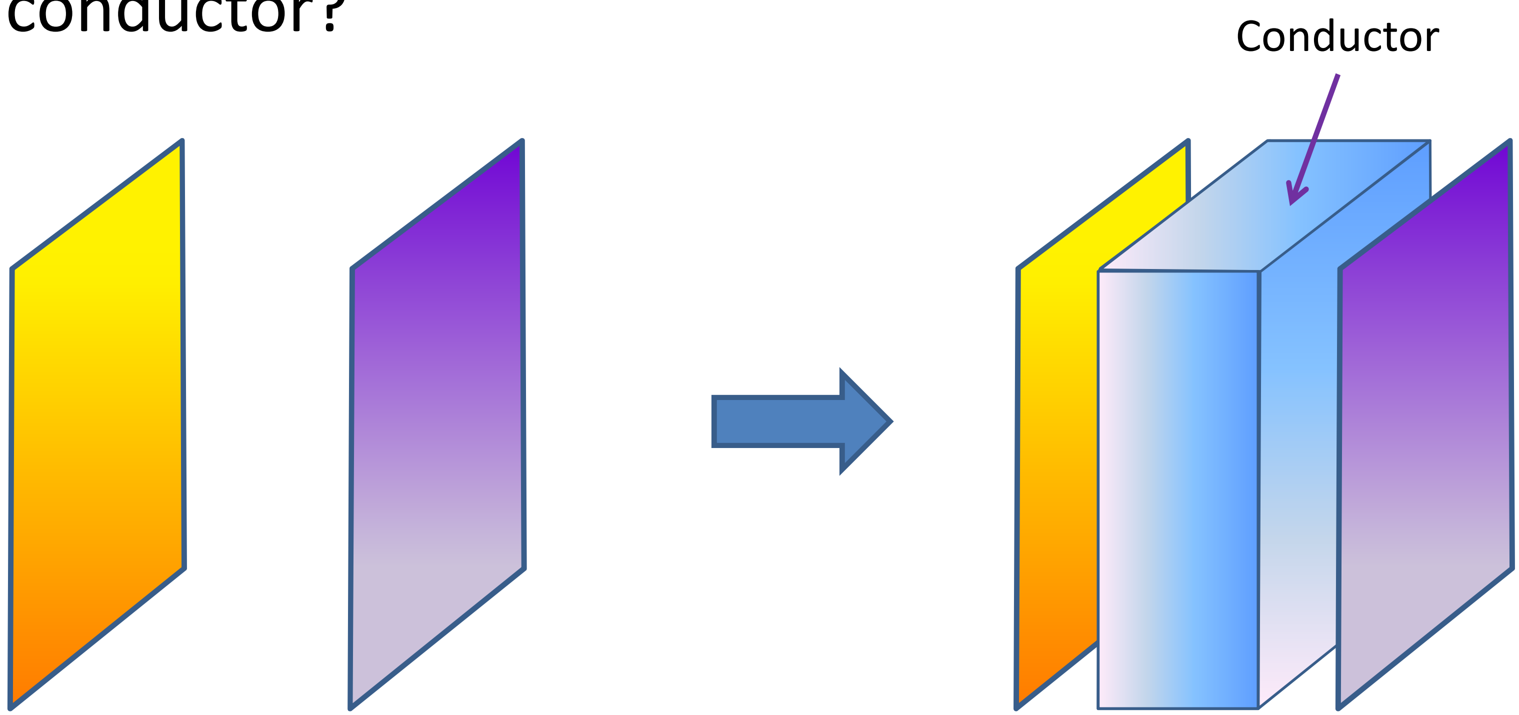
(b) $C_{equiv} = \frac{3}{2}C$

(c) $C_{equiv} = 3C$

(d) $C_{equiv} = \frac{1}{3}C$

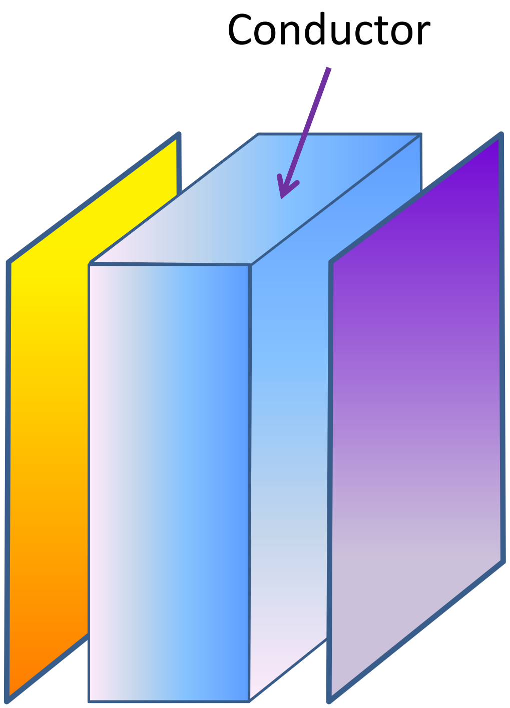
Another Question

- How would the capacitance of a parallel plate capacitor change if we replaced half the space with a conductor?



(a) It would double (b) It would be half (c) No change

Adding Conducting Material



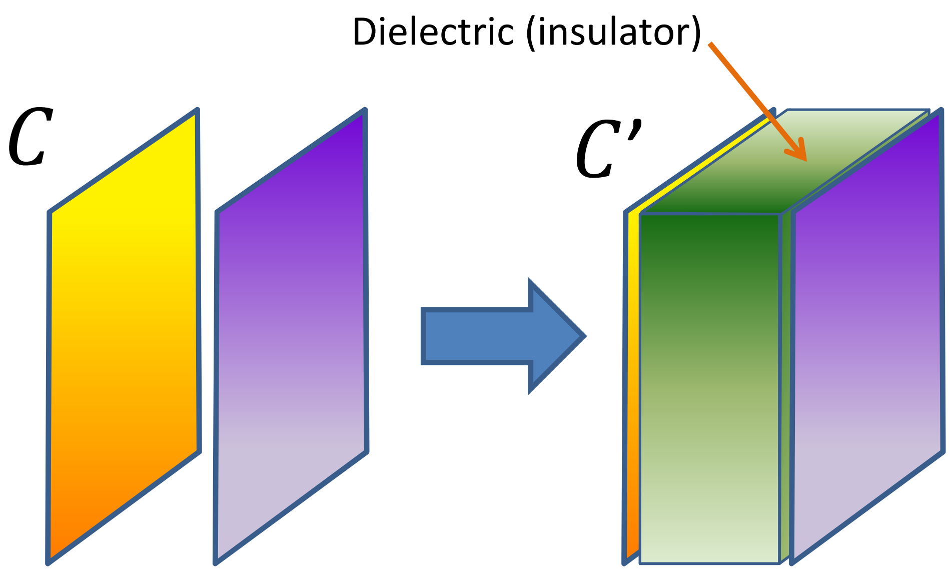
$$C' = \frac{\epsilon_0 A}{(d/4)} = 4C$$

$$C_{equiv} = \left(\frac{1}{C'} + \frac{1}{C'}\right)^{-1} = \frac{1}{2} \times 4C = 2C$$

- The capacitance would double.

Adding an Insulating Material (Dielectric)

- Empirical observation: inserting a dielectric material *reduces* the electric potential difference.
- If Q is constant, the capacitance must increase.
- The "dielectric constant", κ, of the material is the ratio of the capacitance when the space between the conductors is filled with the dielectric material, to the original capacitance.



$$\kappa = \frac{C'}{C} > 1$$

$$C = \frac{\kappa \epsilon_0 A}{d}$$

Permittivity

- The ratio κ is called the dielectric constant.
- We can define

$$\epsilon = \kappa \epsilon_0$$

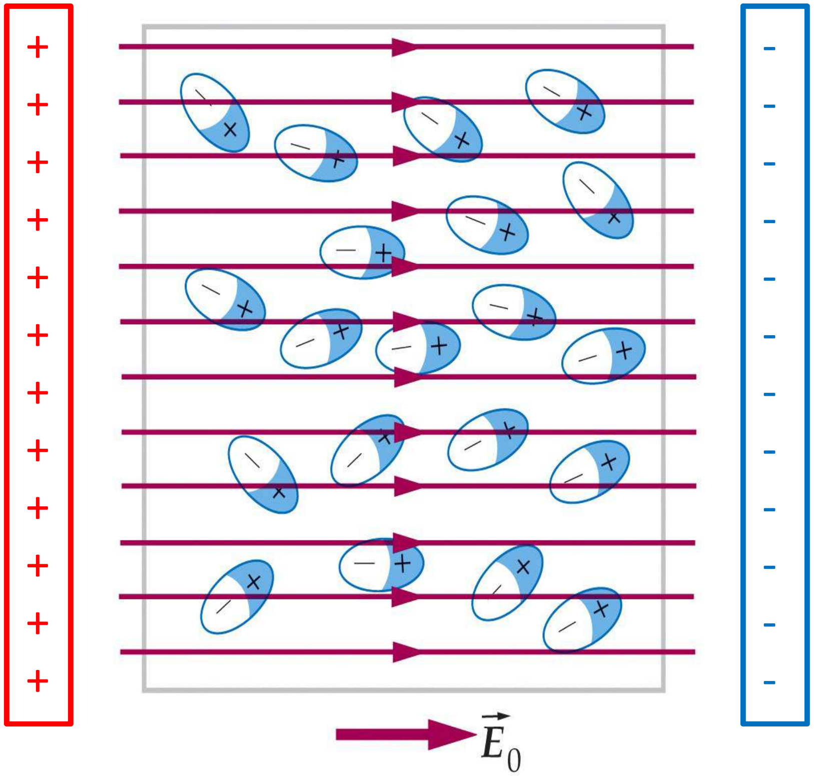
which is called the permittivity of the material with dielectric constant κ.

- We can replace ϵ_0 with ϵ in formulas when the space between conductors is not vacuum.
- For example, the parallel plate capacitor…

$$C = \frac{\epsilon_0 A}{d} \quad \Longrightarrow \quad C = \frac{\epsilon\, A}{d}$$

Why?

- Remember the electric dipole? Insulators in an electric field are composed of electric dipoles:



The dipoles line up with the electric field lines.

The surface charge on the dielectric partially cancels the charge on the plates of the capacitor.

The effective Q is reduced.

$C = Q/V$ decreases.

Dielectric Breakdown

- If the electric field is too strong, it can ionize the dielectric (rip electrons off its molecules).
- Free electrons = conductor... (sparks).
- Can result in damage to the dielectric.
- ***DIELECTRIC STRENGTH***: maximum *electric field* a dielectric can tolerate before breaking down.
- ***BREAKDOWN POTENTIAL***: maximum *electric potential* a device can tolerate before breaking down.

Dielectric Constants

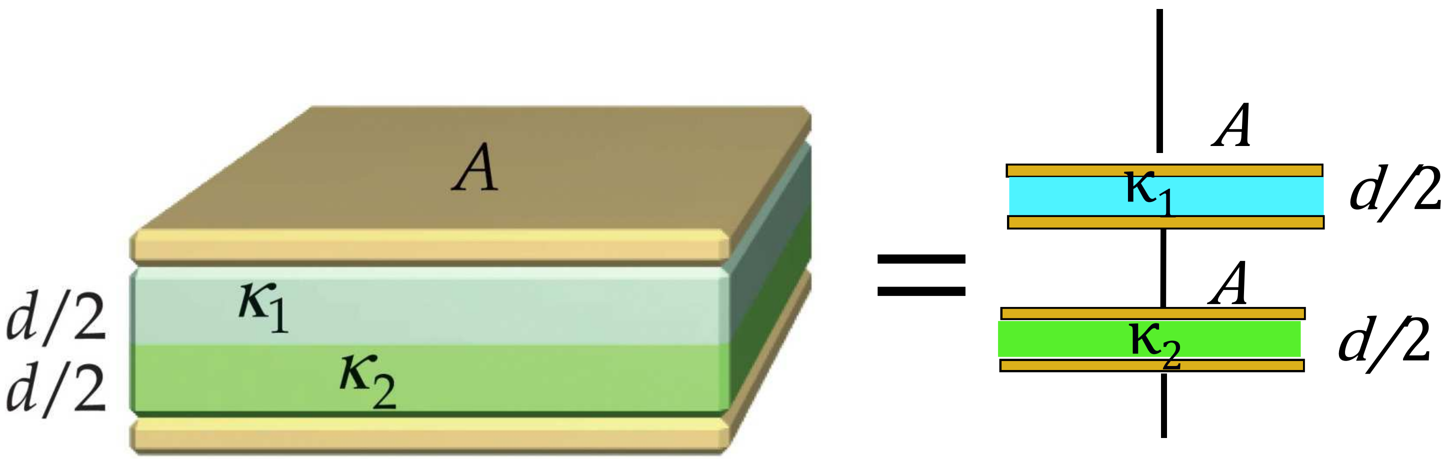
material	κ	dielectric strength (kV/mm)
air (1 atm)	1.00054	3
paraffin	2.1–2.5	10
glass (Pyrex)	5.6	14
mica	5.4	10–100
polystyrene	2.55	24
H_2O (20^0 C)	80	?
Strontium titanate	240	8
Sulfur hexafluoride	1.002026	9

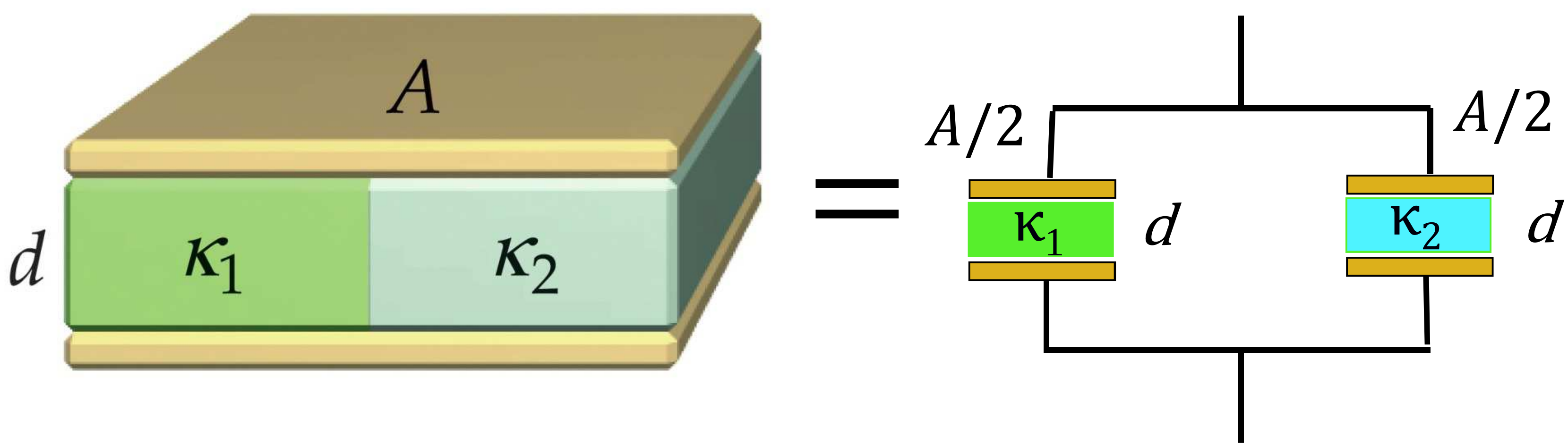
Preventing Electrical Discharge

- The PRIME lab in the basement uses a tandem Van de Graaff generator to accelerate atomic fragments.
- It is full of Sulfur Hexafluoride to increase the breakdown potential.

- For more fun with Sulfur Hexafluoride, check out http://www.youtube.com/watch?v=u19QfJWI1oQ

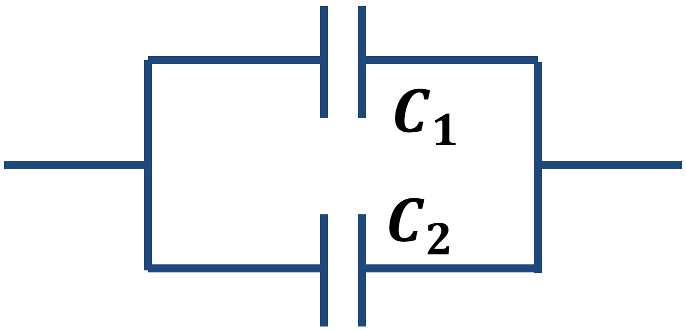
Dielectric Combinations





Summary

- Capacitors in parallel:



$$C = C_1 + C_2$$

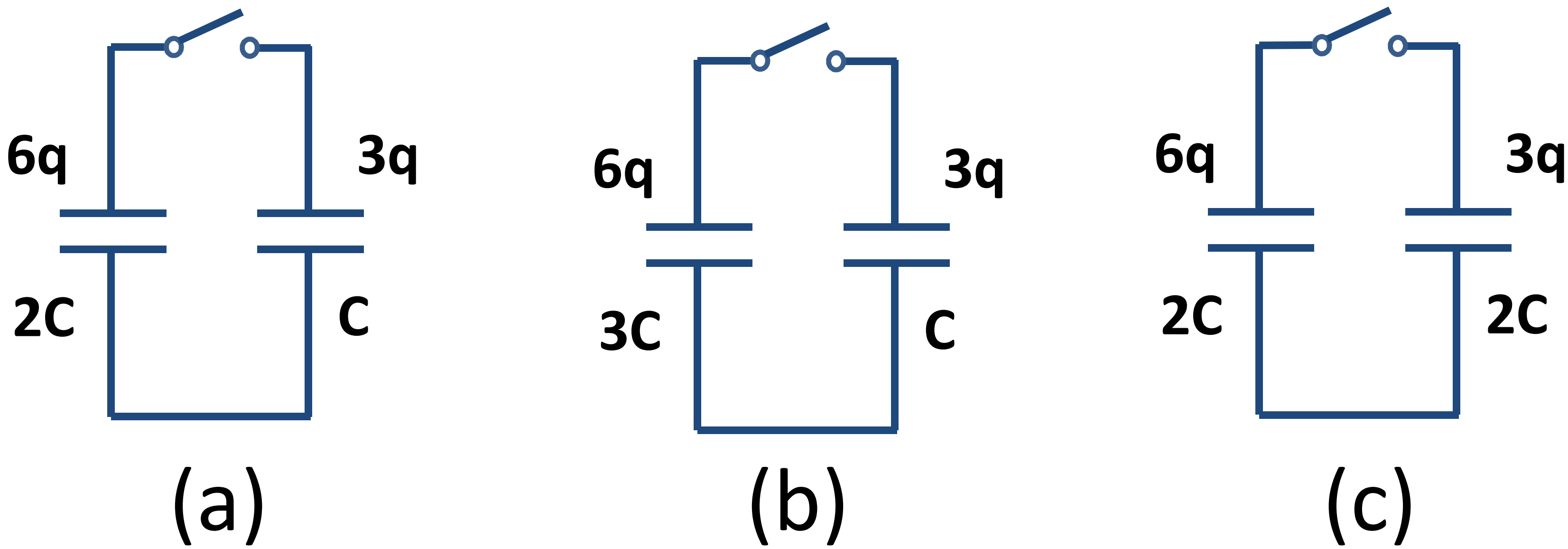
- Capacitors in series:

$$C = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1}$$

- Dielectrics increase capacitance: $\kappa > 1$

Question:

- Three circuits, consisting of two capacitors and a switch, are initially charged as indicated.
- After the switches are closed, in which circuit will the charge on the **left** *increase*?



(d) None of them