Physics 212
Lecture 8

Today's Concept:

Capacitors

(Capacitors in a circuits, Dielectrics, Energy in capacitors)

Your Comments

Overall easy and fun pre-lecture!

I'm still pretty confused on how to do networks of capacitors where there are capacitors in parallel and in series. It would help a lot if we went over these in lecture!

Will we cover dielectric breakdown in this class? (I am not trying to prompt a dangerous experiment, but that sounds like the most direct answer to this question.)

Can charge only move through a dielectric if the capacitor is connected to a battery?

I'm allowed to say this because I'm an engineer too: It's not like we had Valentine's Day plans anyways.... Exam 1 here we come!

when in lecture please clearly distinguish the variable changes when the capacitor is isolated and not.

the capacitor in circuit, i have no idea which properties stay the same and which change. please explain it.

I don't have anything that I really didn't understand, so enjoy a (bad) joke: One capacitor punches another and gets charged with battery.

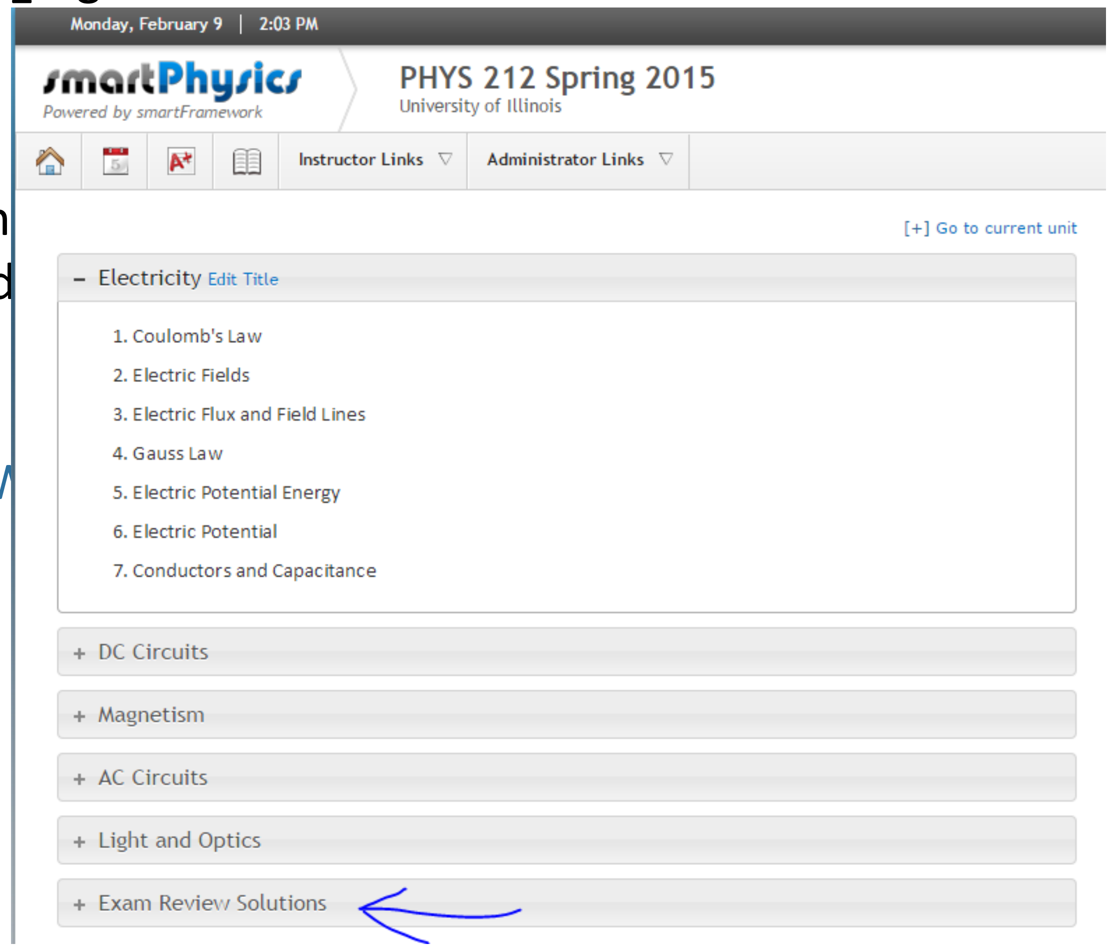
Please explain how to identify series and parallel capacitors base on the diagram.... I am a little confused about them..

Exam Logistics

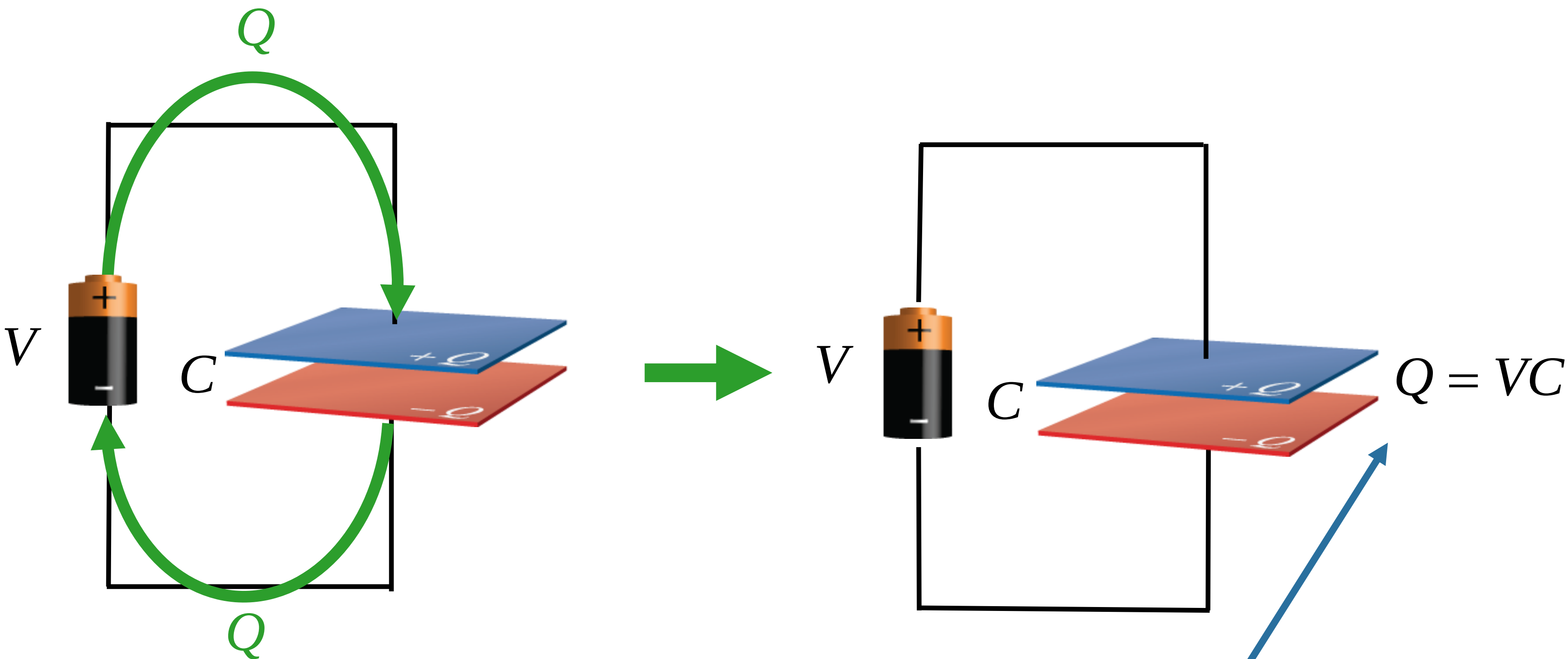
1) EXAM 1: WED February 18th at 7pm
   - Sign Up in Gradebook for Conflict Exam at 5:15pm if desired
   - If you have double conflict please email Prof. Ben Hooberman
   - MATERIAL: Lectures 1 - 8

2) EXAM 1 PREPARATION
   - Study HW, Discussion
   - Old Exams are a good
   - See SmartPhysics for

3) Extra Office Hours (Tuesday/ W
   rooms/times)

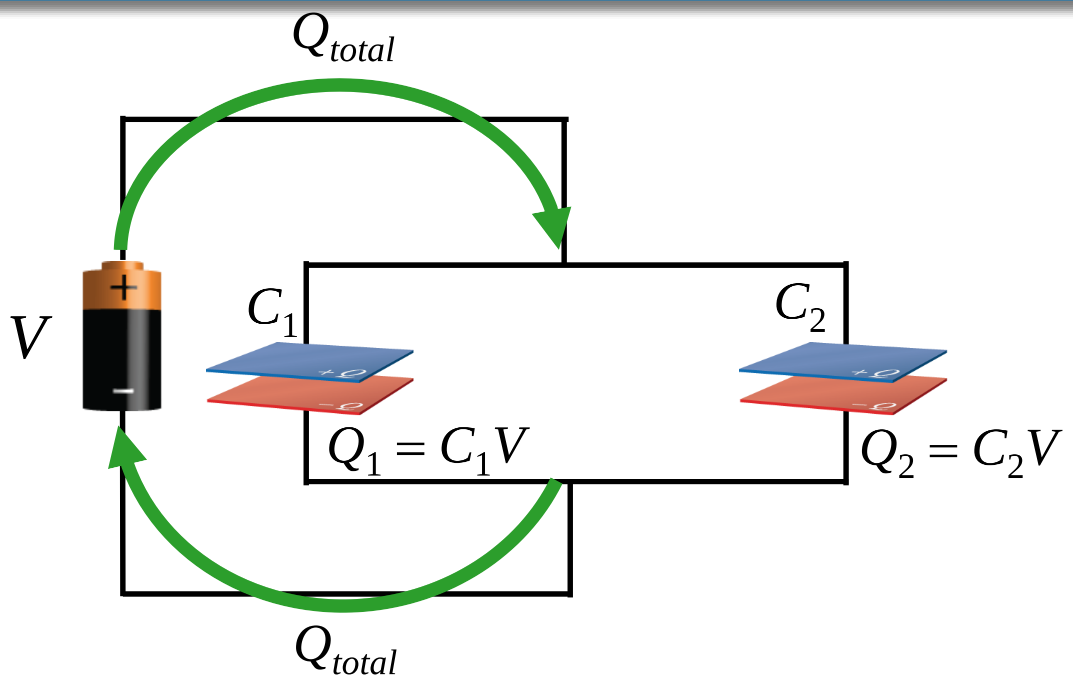


Simple Capacitor Circuit



This "Q" really means that the battery has moved charge Q from one plate to the other, so that one plate holds $+Q$ and the other $-Q$.

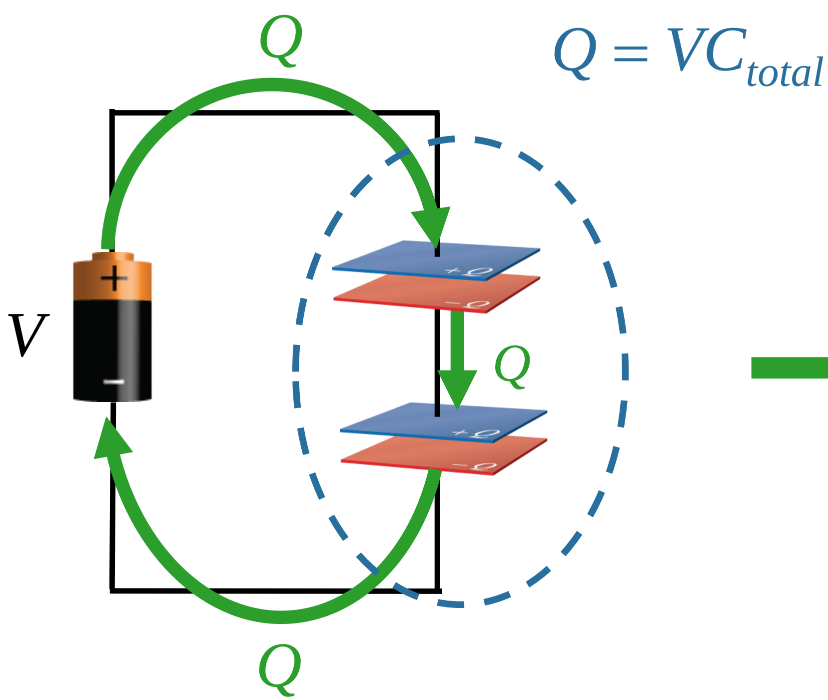
Parallel Capacitor Circuit

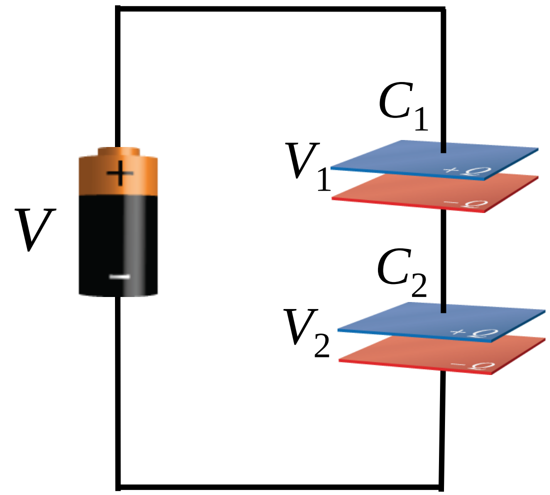


Key point: V is the same for both capacitors

Key Point: $Q_{total} = Q_1 + Q_2 = VC_1 + VC_2 = V\underbrace{(C_1 + C_2)}_{C_{total} = C_1 + C_2}$

Series Capacitor Circuit





Key point: Q is the same for both capacitors

Key point: $Q = VC_{total} = V_1C_1 = V_2C_2$

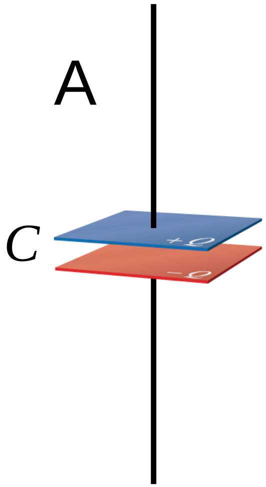
Also: $V = V_1 + V_2$ $\longrightarrow$ $Q/C_{total} = Q/C_1 + Q/C_2$

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2}$$

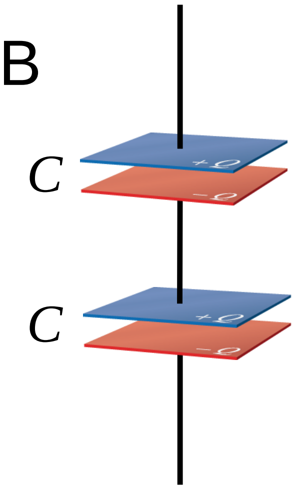
CheckPoint 1

Which has lowest total capacitance:

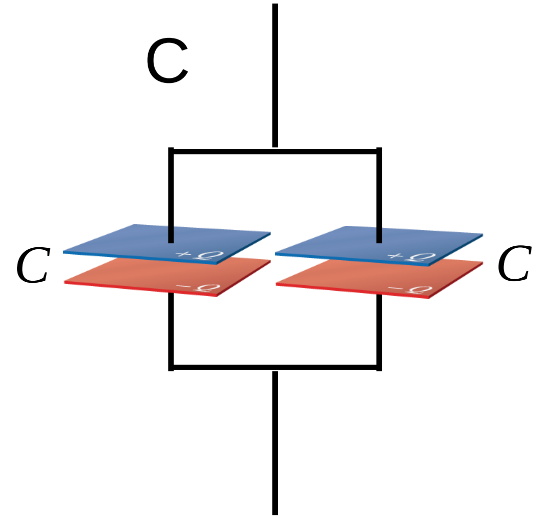
A



B



C



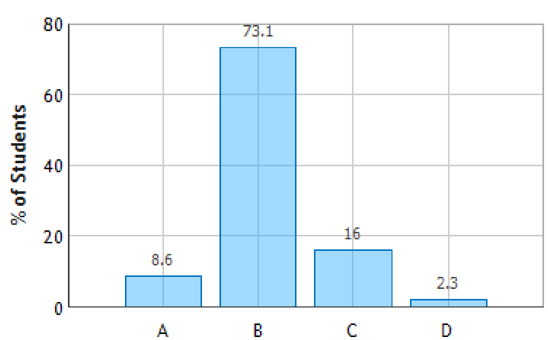
$$C_{total} = C$$

$$1/C_{total} = 1/C + 1/C$$
$$= 2/C$$

$$\boxed{C_{total} = C/2}$$

$$C_{total} = 2C$$

Three Capacitor Configurations: Question 1 (N = 789)

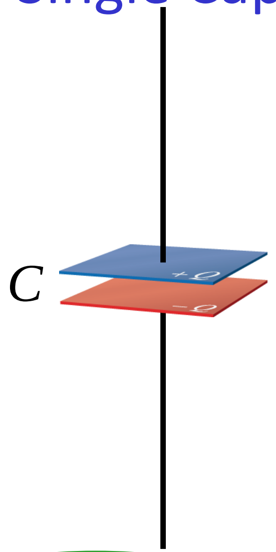


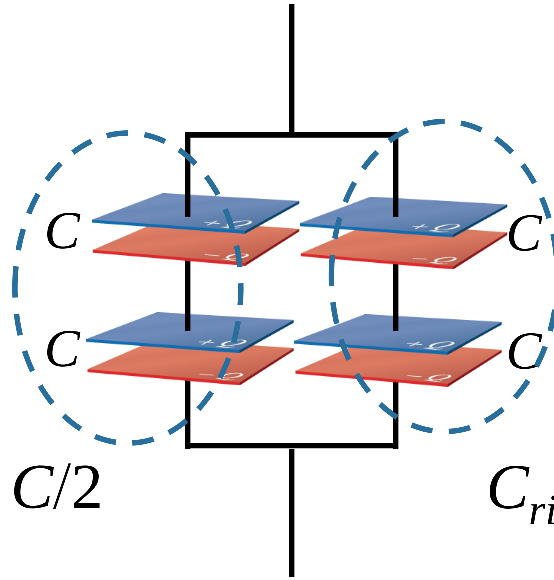
CheckPoint 2

Which has lowest total capacitance?

A) Single Capacitor B) 4 Capacitors C) Same

:



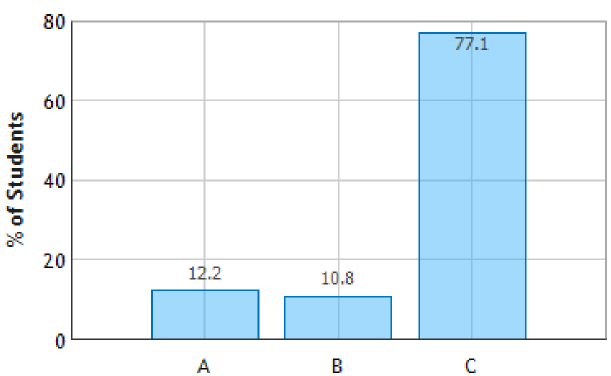


$C_{left} = C/2$ $C_{right} = C/2$

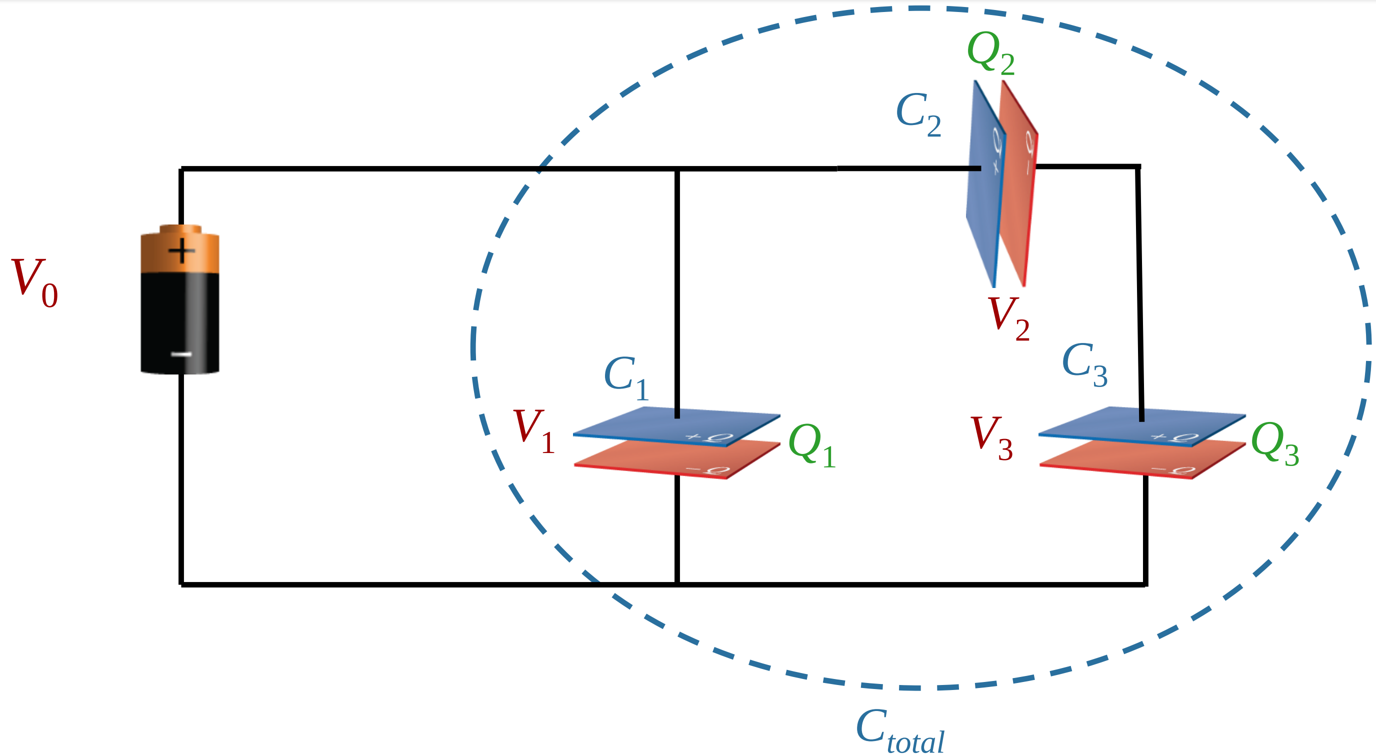
$C_{total} = C$

$C_{total} = C_{left} + C_{right}$

$C_{total} = C$



Similar to CheckPoint 3



Which of the following is NOT necessarily true:

A) $V_0 = V_1$

B) $C_{total} > C_1$

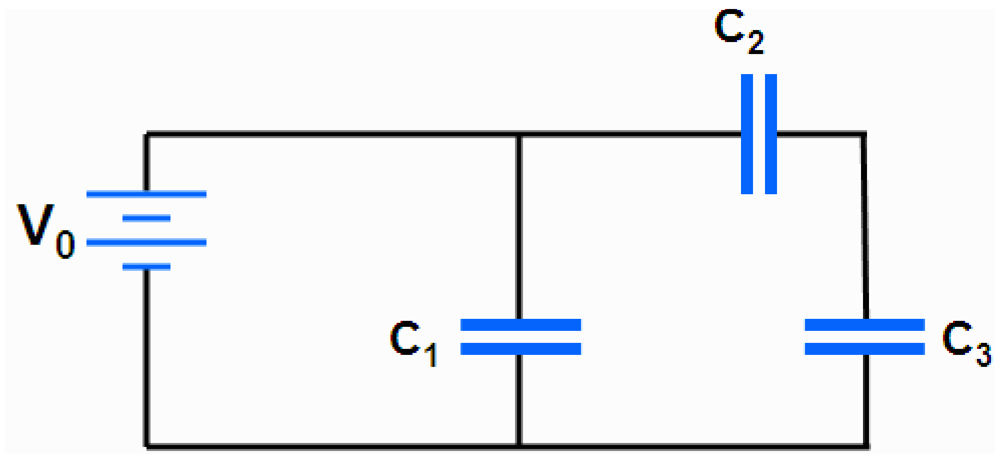
C) $\boxed{V_2 = V_3}$

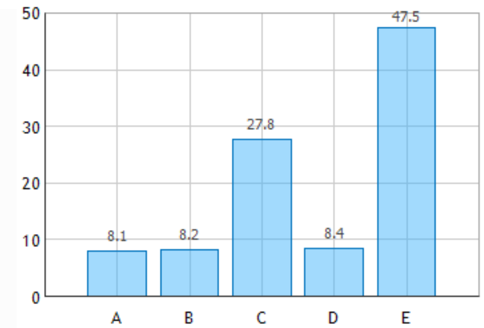
D) $Q_2 = Q_3$

E) $V_1 = V_2 + V_3$

CheckPoint 3

A circuit consists of three unequal capacitors C_1, C_2, and C_3 which are connected to a battery of voltage V_0. The capacitance of C_2 is twice that of C_1. The capacitance of C_3 is three times that of C_1. The capacitors obtain charges Q_1, Q_2, and Q_3.





~~A.~~ $Q_1 > Q_3 > Q_2$ ~~B.~~ $Q_1 > Q_2 > Q_3$ **C.** $Q_1 > Q_2 = Q_3$ **D.** $Q_1 = Q_2 = Q_3$ **E.** $\boxed{Q_1 < Q_2 = Q_3}$

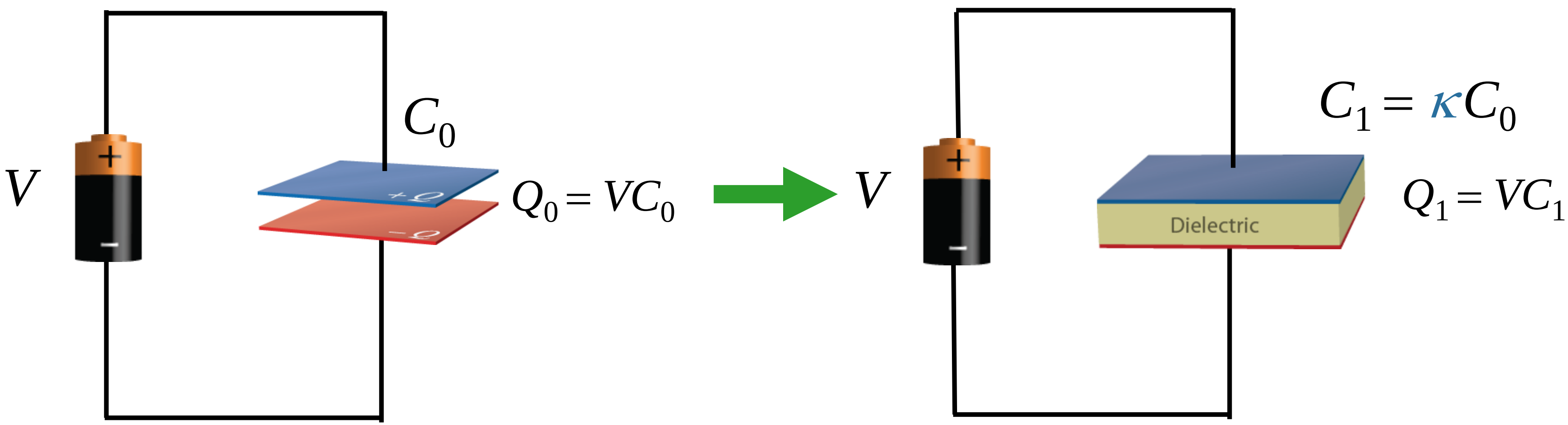
1. : $Q_2 = Q_3$ (capacitors in series)

2. How about Q_1 vs. Q_2 and Q_3? Calculate C_{23} first.

$$\frac{1}{C_{23}} = \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{2C_1} + \frac{1}{3C_1} = \frac{5}{6C_1} \Rightarrow \boxed{C_{23} = \frac{6}{5}C_1} \Rightarrow$$

$$\boxed{\begin{aligned} Q_1 &= C_1V_0 \\ Q_{23} &= Q_2 = Q_3 = C_{23}V_0 = \frac{6}{5}C_1V_0 \end{aligned}}$$

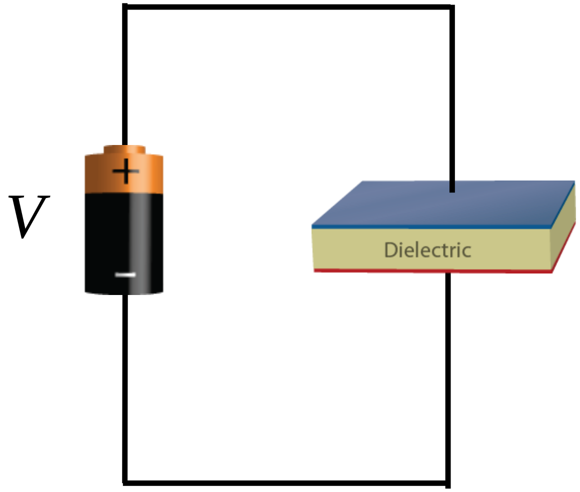
Dielectrics



By adding a dielectric you are just making a new capacitor with larger capacitance (factor of κ)

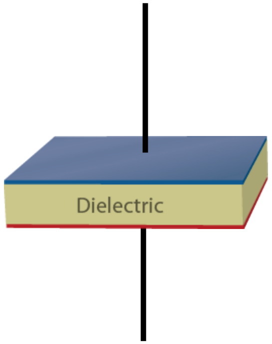
Messing with Capacitors

If connected to a battery V stays constant



$$V_1 = V$$
$$C_1 = \kappa C$$
$$\Rightarrow Q_1 = C_1 V_1 = \kappa C V = \kappa Q$$

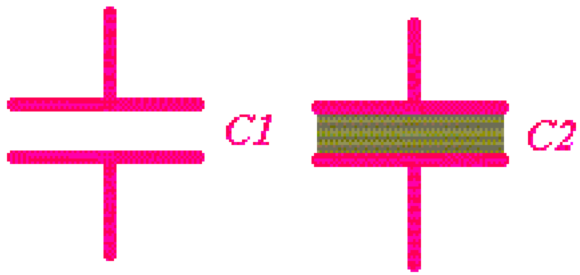
If isolated then total Q stays constant



$$Q_1 = Q$$
$$C_1 = \kappa C$$
$$\Rightarrow V_1 = Q_1 / C_1 = Q/\kappa C = V/\kappa$$

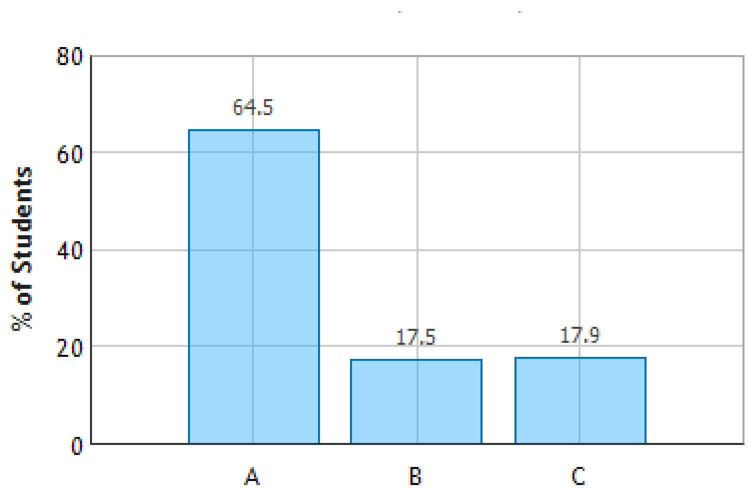
CheckPoint 4a

Two identical parallel plate capacitors are given the same charge Q, after which they are disconnected from the battery. Then, a dielectric is placed between the plates of C_2



Compare the voltages of the two capacitors.

A $V_1 > V_2$ B $V_1 = V_2$ C $V_1 < V_2$



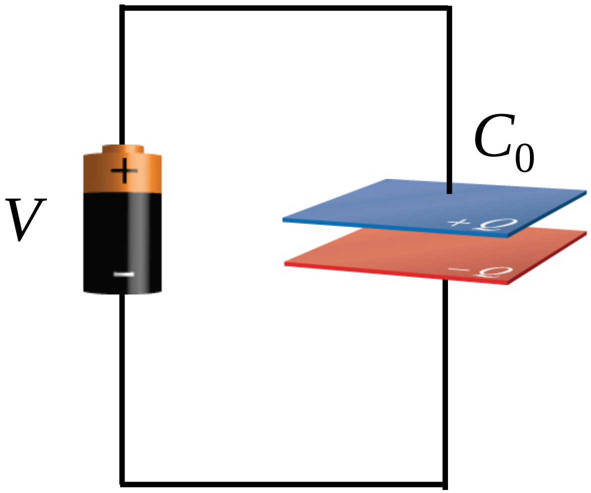
"The addition of a dielectric will increase the capacitance of C2, thereby decreasing its voltage b the equation C=Q/V.."

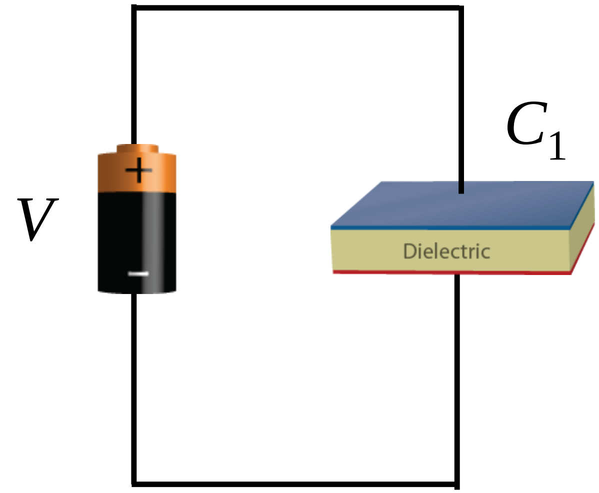
"V remains constant through the addition of dielectrics. As foretold by the pre-lecture prophesy

"By adding in the dielectric we are cutting down the distance between the two plates. a lower distance means the plates are higher in voltage."

Messing with Capacitors Clicker Question

Two identical parallel plate capacitors are connected to identical batteries. Then a dielectric is inserted between the plates of capacitor C_1. Compare the energy stored in the two capacitors.





A) $U_1 < U_0$

B) $U_0 = U_1$

C) $U_1 > U_0$

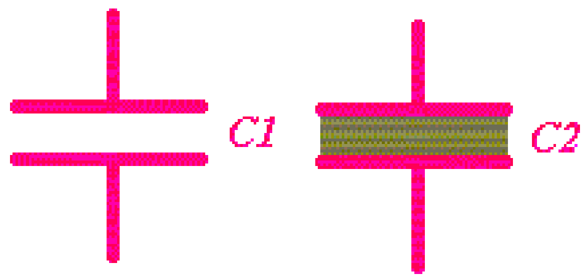
Compare using $U = {}^1\!/_2 CV^2$

$$U_1/U_0 = \kappa$$

Potential Energy goes UP

CheckPoint 4b

Two identical parallel plate capacitors are given the same charge Q, after which they are disconnected from the battery. Then, a dielectric is placed between the plates of C_2



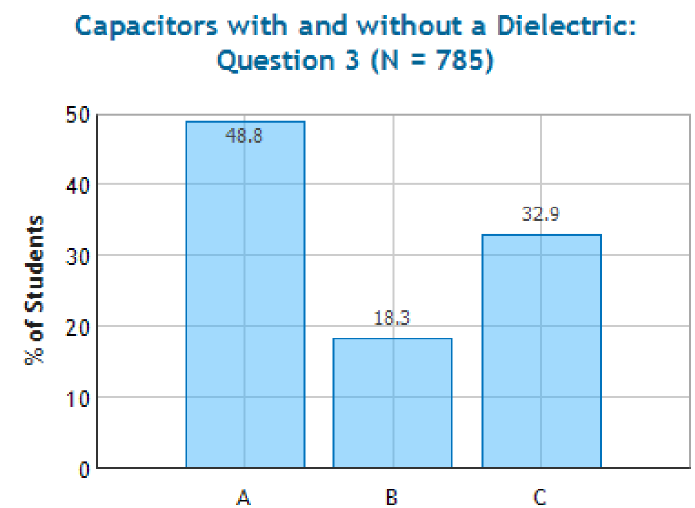
Compare the potential energy stored by the two capacitors.

A) $U_1 > U_2$ B) $U_1 = U_2$ C) $U_1 < U_2$

U=(0.5)QV. As we know that V2 is smaller than V1.

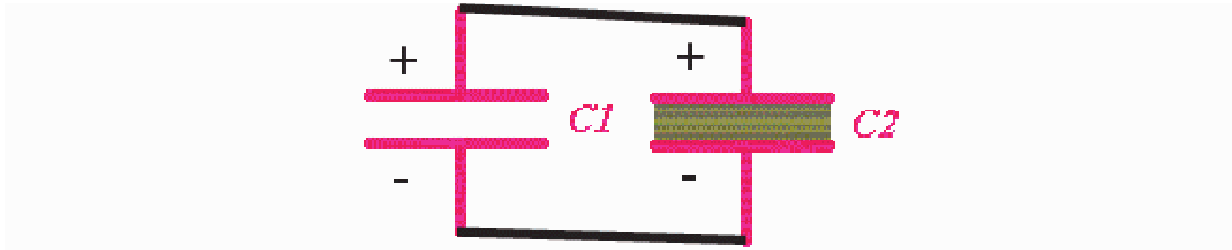
Since there is no battery to supply additional energy, they have the same amount of stored energy.

Since the capacitance of 2 is greater than 1 and the V's are equal then the charge on 2 must increase and therefore U2 is greater than U1



CheckPoint 4c

Two identical parallel plate capacitors are given the same charge Q, after which they are disconnected from the battery. After C_2 has been charged and disconnected, it is filled with a dielectric. **The two capacitors are now connected to each other by wires as shown. How will the charge redistribute itself, if at all?**



A. The charges will flow so that the charge on C_1 will become equal to the charge on C_2.

B. The charges will flow so that the energy stored in C_1 will become equal to the energy stored in C_2.

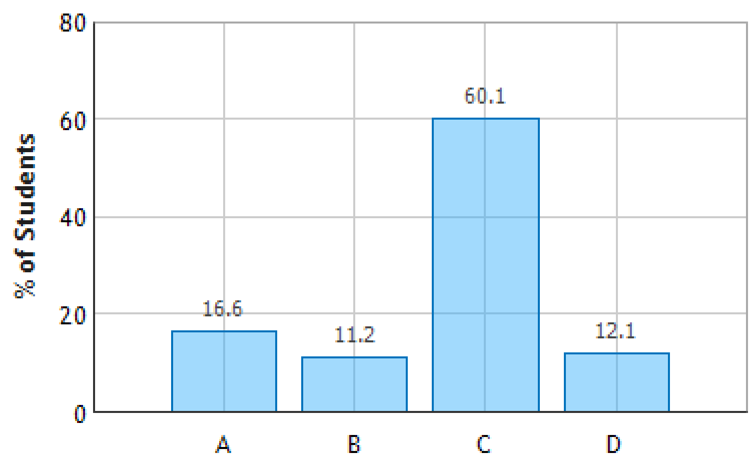
C. The charges will flow so that the potential difference across C_1 will become the same as the potential difference across C_2.

D. No charges will flow. The charge on the capacitors will remain what it was before they were connected.

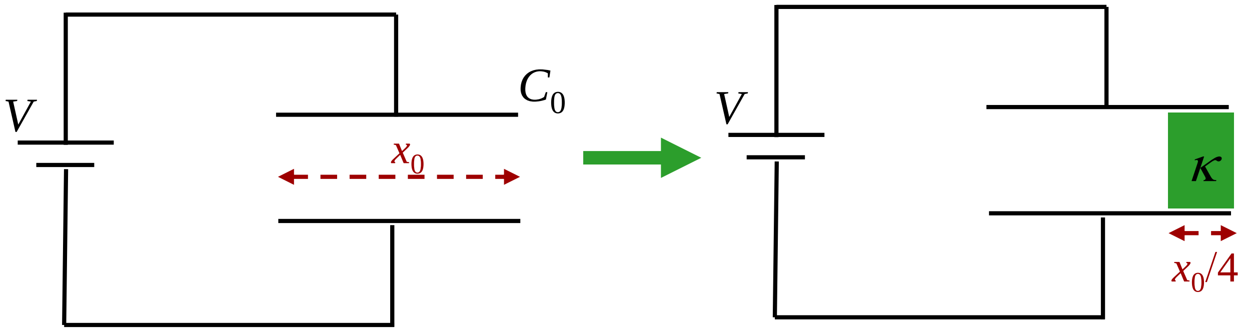
V must be the same !!

Q: $$\frac{Q_1}{C_1} = \frac{Q_2}{C_2} \quad \Rightarrow \quad \boxed{Q_1 = \frac{C_1}{C_2} Q_2}$$

U: $$U_1 = \tfrac{1}{2} C_1 V^2 \qquad U_2 = \tfrac{1}{2} C_2 V^2 \quad \Rightarrow \quad \boxed{U_1 = \frac{C_1}{C_2} U_2}$$



Calculation



An air-gap capacitor, having capacitance C_0 and width x_0 is connected to a battery of voltage V.

A dielectric (κ) of width $x_0/4$ is inserted into the gap as shown.

What is Q_f, the final charge on the capacitor?

Conceptual Analysis:

$$C \equiv \frac{Q}{V}$$

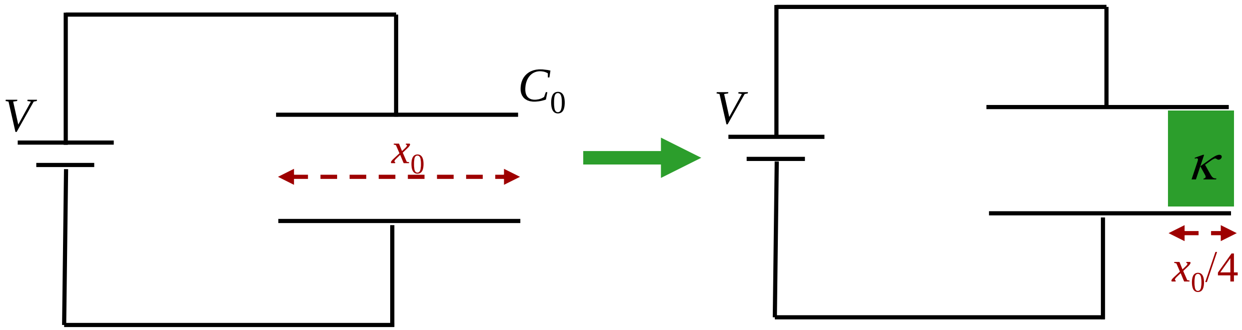
What changes when the dielectric added?

A) Only C B) only Q C) only V $\boxed{\text{D) } C \text{ and } Q}$ E) V and Q

Adding dielectric changes the physical capacitor → C changes

V does not change and C changes → Q changes

Calculation



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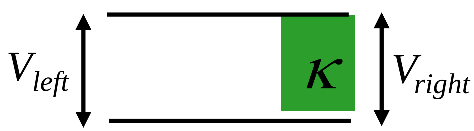
Strategic Analysis:

- Calculate new capacitance C
- Apply definition of capacitance to determine Q

To calculate C, let's first look at:



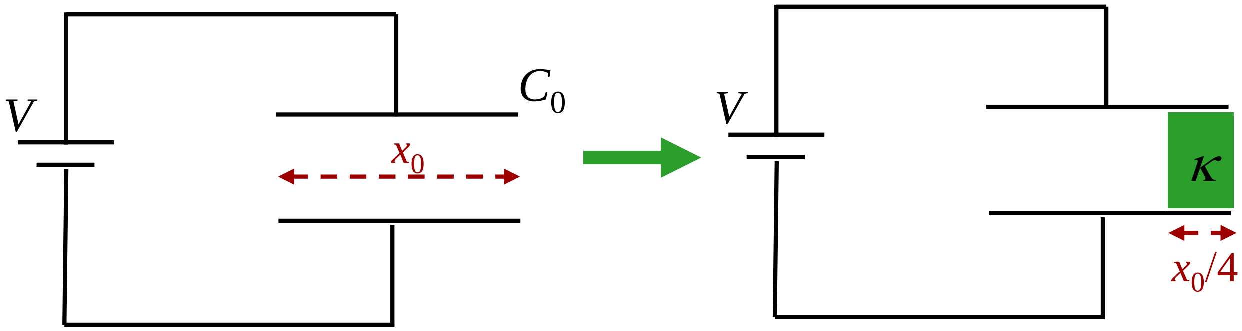
A) $V_{left} < V_{right}$

B) $\boxed{V_{left} = V_{right}}$

C) $V_{left} > V_{right}$

The conducting plate is an equipotential !

Calculation



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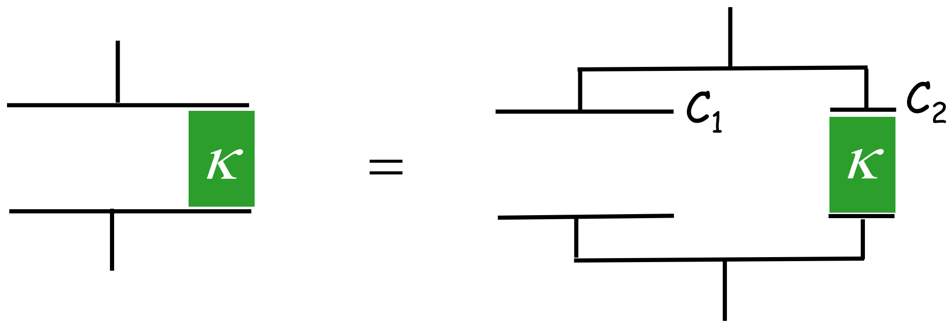
Can consider capacitor to be two capacitances, C_1 and C_2, in parallel



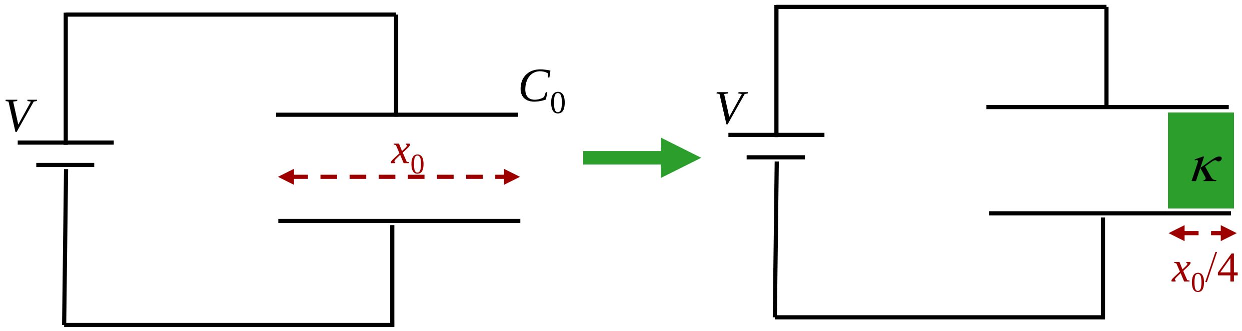
What is C_1 ?

A) $C_1 = C_0$ $\boxed{\text{B) } C_1 = {}^3/_4 C_0}$ C) $C_1 = {}^4/_3 C_0$ D) $C_1 = {}^1/_4 C_0$

In general. For parallel plate capacitor: $C = \varepsilon_0 A/d$

$$\left.\begin{array}{l} A = {}^3/_4 A_0 \\ d = d_0 \end{array}\right] \Rightarrow C_1 = {}^3/_4 (\varepsilon_0 A_0/d_0) \Rightarrow \boxed{C_1 = {}^3/_4 C_0}$$

Calculation



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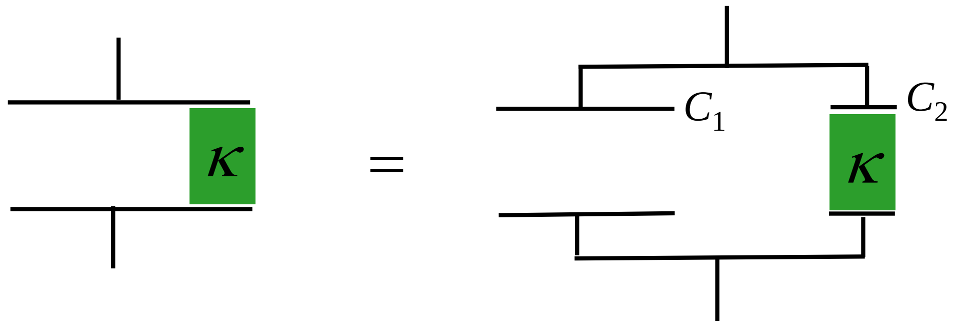


$C_1 = {}^3/_4 C_0$

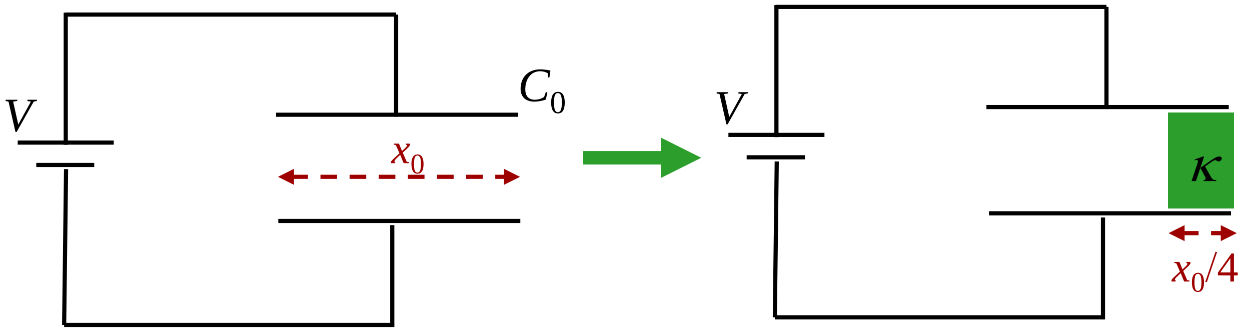
What is C_2 ?

A) $C_2 = \kappa C_0$ B) $C_2 = {}^3/_4\, \kappa C_0$ C) $C_2 = {}^4/_3\, \kappa C_0$ $\boxed{\text{D) } C_2 = {}^1/_4\, \kappa C_0}$

In general. For parallel plate capacitor filled with dielectric: $C = \kappa\varepsilon_0 A/d$

$$\left.\begin{array}{c} A = {}^1/_4 A_0 \\ d = d_0 \end{array}\right] \rightarrow C = \tfrac{1}{4}(\kappa\varepsilon_0 A_0/d_0) \rightarrow C_2 = {}^1/_4\, \kappa C_0$$

Calculation



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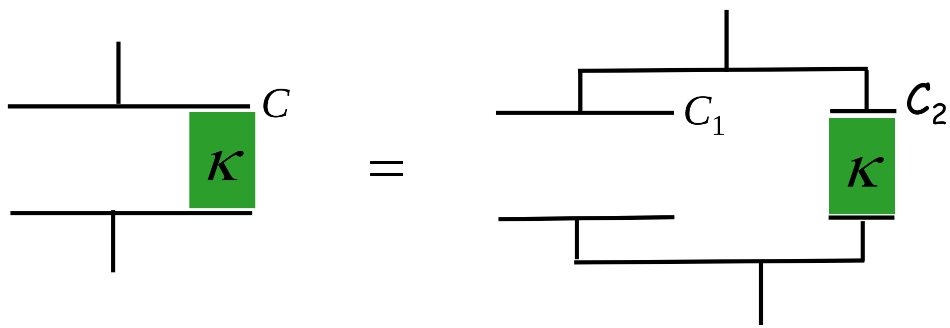


$C_1 = {}^3/_4 C_0$ $\qquad$ $C_2 = {}^1/_4\, \kappa C_0$

What is C?

A) $\boxed{C = C_1 + C_2}$

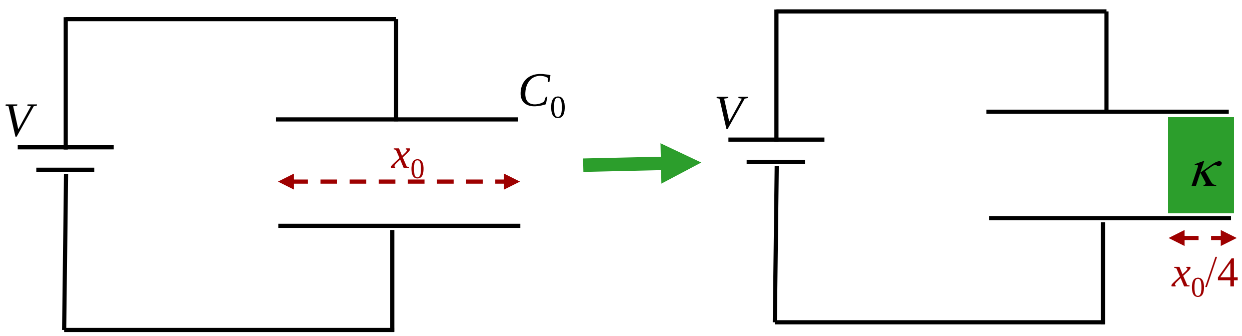
B) $C = C_1 + \kappa C_2$

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

$C =$ parallel combination of C_1 and C_2: $\quad C = C_1 + C_2$

$\rightarrow \quad C = C_0\, ({}^3/_4 + {}^1/_4\, \kappa)$

Calculation



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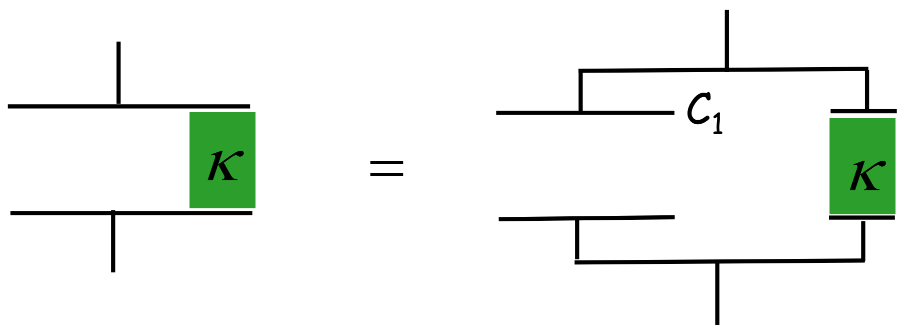

$C_1 = {}^3/_4 C_0$ $\qquad$ $C_2 = {}^1/_4\, \kappa C_0$

$$\rightarrow \quad C = C_0\,({}^3/_4 + {}^1/_4\, \kappa)$$

What is Q?

$$C \equiv \frac{Q}{V} \quad \rightarrow \quad Q = VC$$

$$Q_f = VC_0\left(\frac{3}{4} + \frac{1}{4}\kappa\right)$$