Your Comments

Overall easy and fun pre-lecture!

Little confused on the difference between voltage and potential energy (isn't it the same thing?).

What if the d is different for the two capacitors connected in parallel?

The first video introducing the dielectric said that inserting a dielectric in between a parallel plate capacitor would decrease the electric field and thus decrease its potential difference. However, the very next video said that potential difference remains the same. How could this be?

I found this prelecture very interesting but also very confusing. Can you please go over the changes that happen in a capacitor when a dielectric is inserted in the space between the plates?

Lecture questions aren't too hard. Prelecture and checkpoint aren't too hard. But the homework...it's so hard. Much more difficult than lecture and prelecture. Why???

OMG exam next week!

Exam Logistics

1) **EXAM 1: WED September 24th 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, Checkpoints
    - Old Exams are a good way to assess what you need to know
    - Prelecture of Fall 2010 solutions available

3) **Extra Office Hours** (Tuesday/ Wednesday next week – see website for rooms/times)

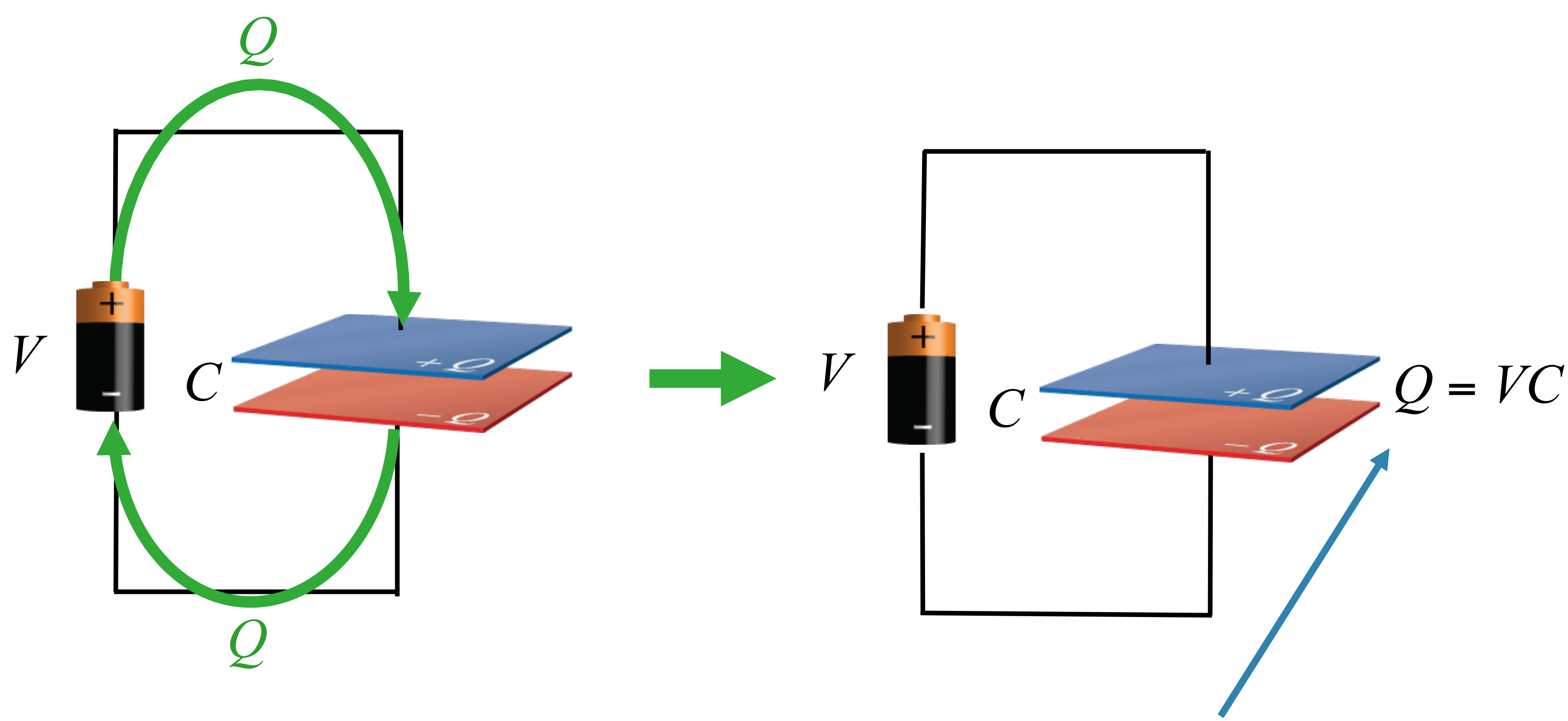
Physics 212
Lecture 8

Today's Concept:

Capacitors

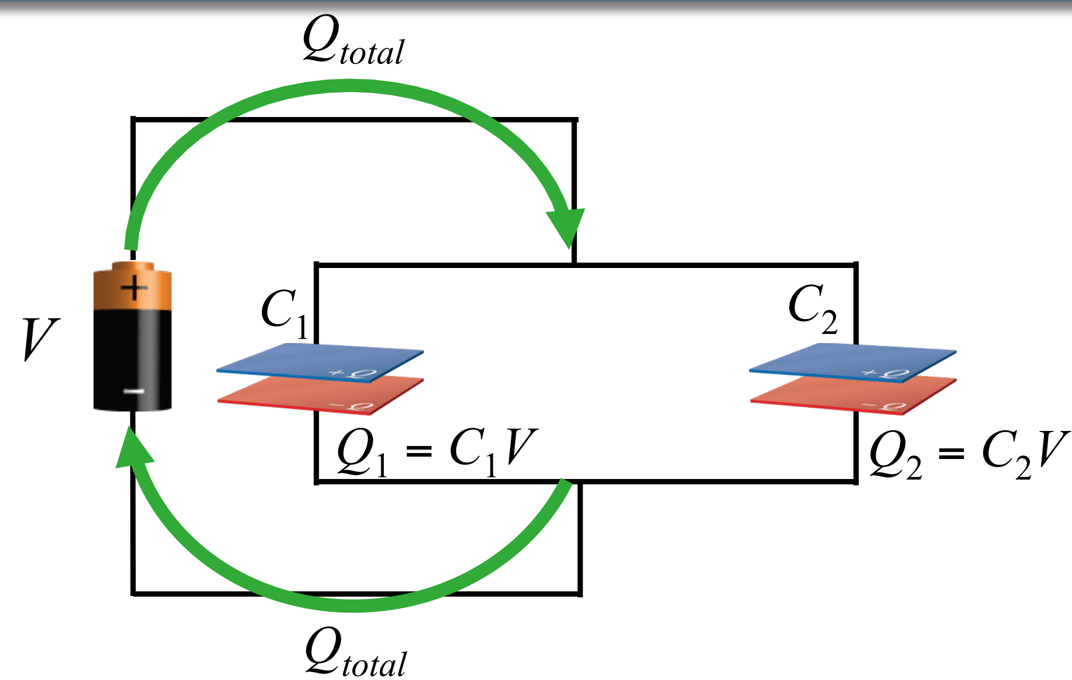
(Capacitors in a circuits, Dielectrics, Energy in capacitors)

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

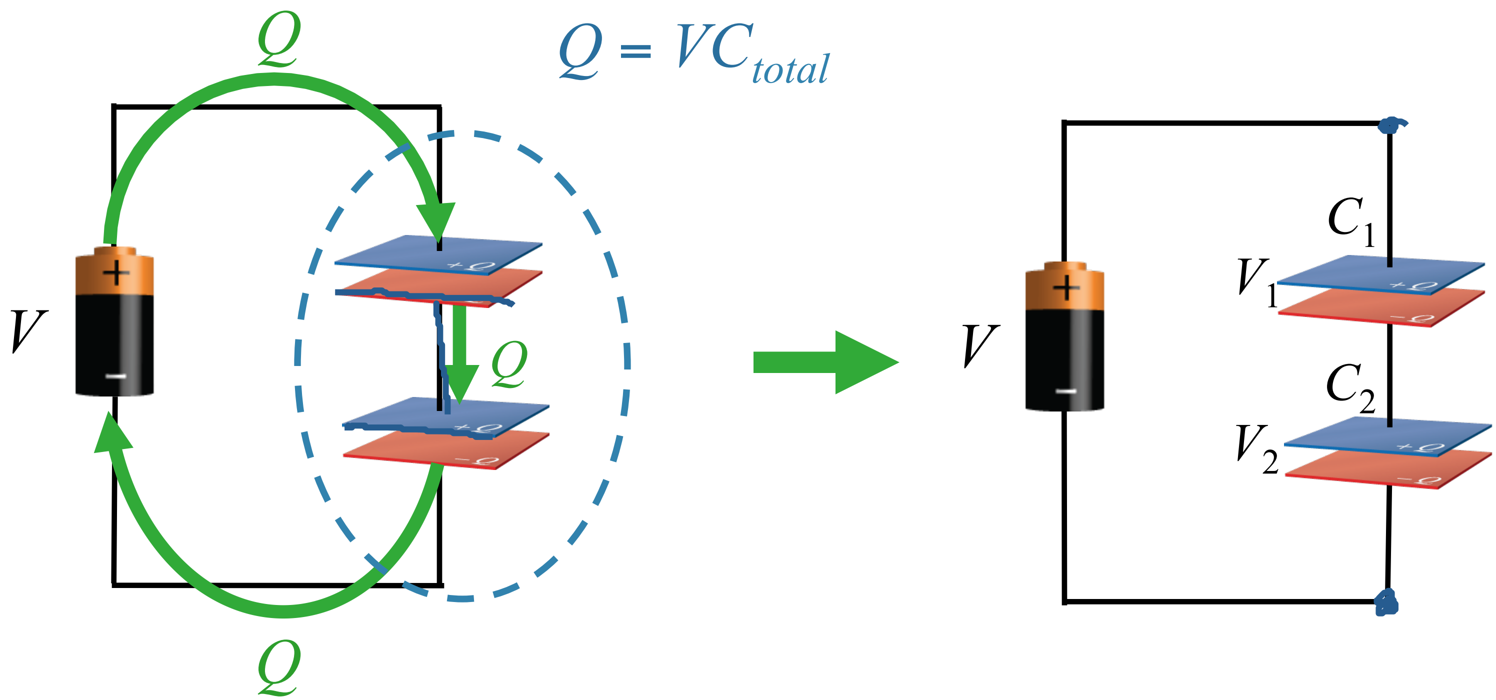


Key point: V is the same for both capacitors

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

$$C_{total} = C_1 + C_2$$

Series Capacitor Circuit



Key point: Q is the same for both capacitors

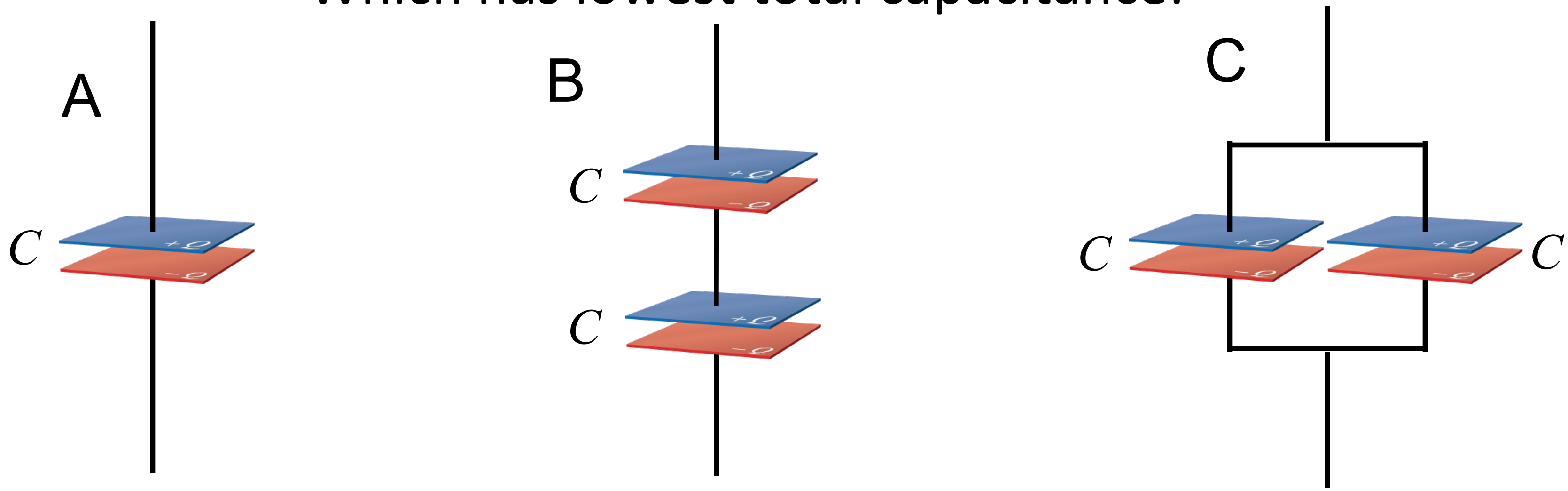
Key point: $Q = VC_{total} = V_1C_1 = V_2C_2$

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

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

CheckPoint 1

Which has lowest total capacitance:

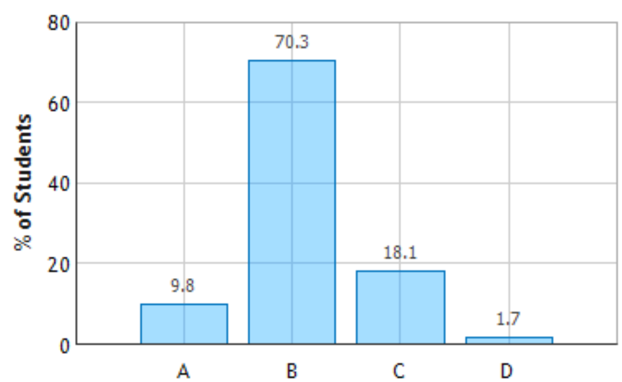


$$1/C_{total} = 1/C + 1/C$$
$$= 2/C$$

$$C_{total} = C$$

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

$$C_{total} = 2C$$



CheckPoint 2

Which has lowest total capacitance?

A) Single Capacitor B) 4 Capacitors C) Same

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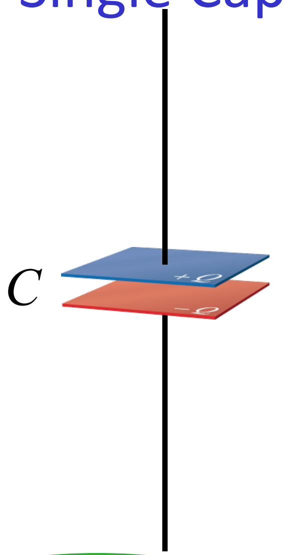
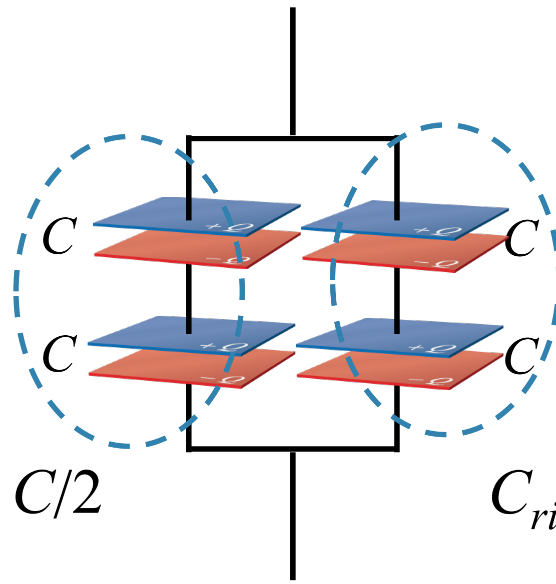


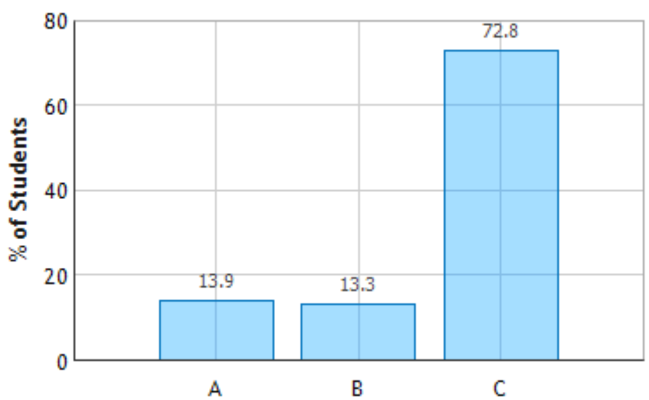
$$C_{total} = C$$



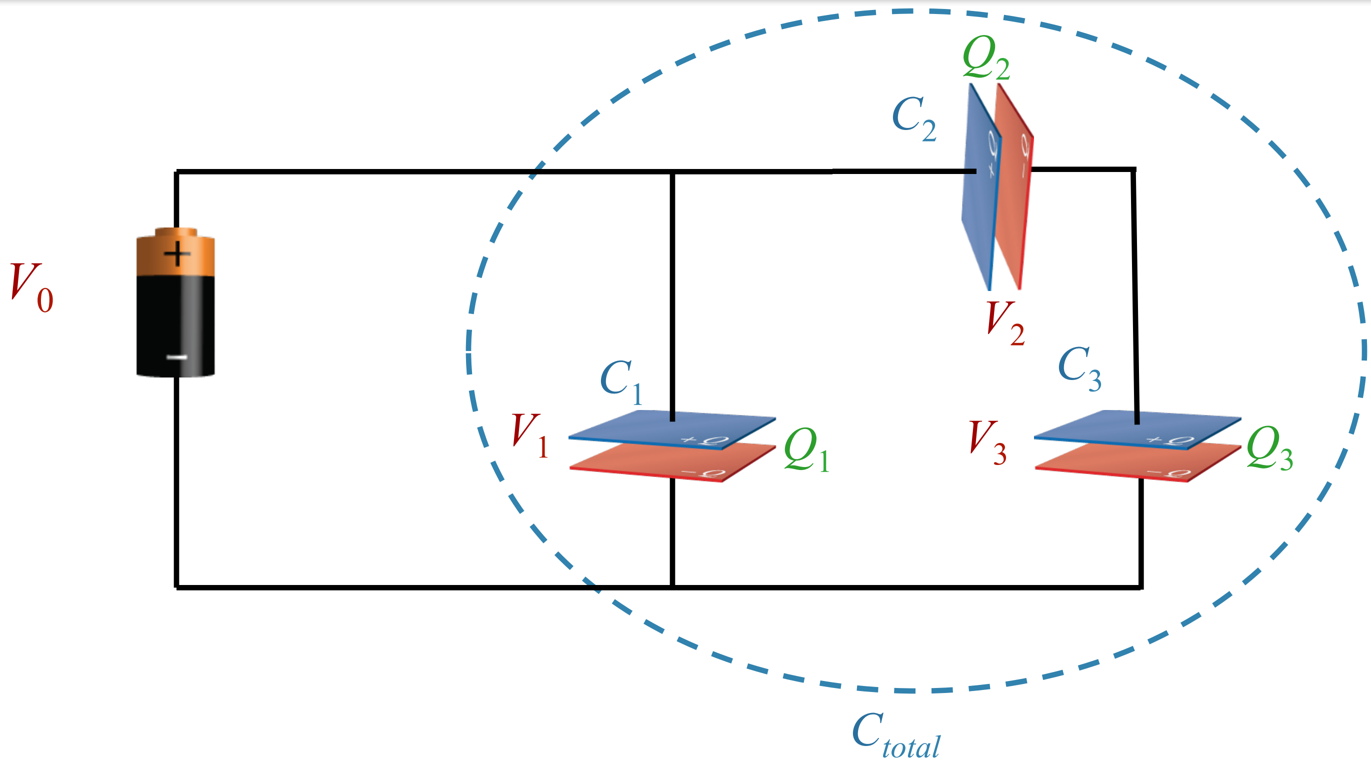
$$C_{left} = C/2 \qquad C_{right} = C/2$$

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

$$C_{total} = C$$



Similar to CheckPoint 3

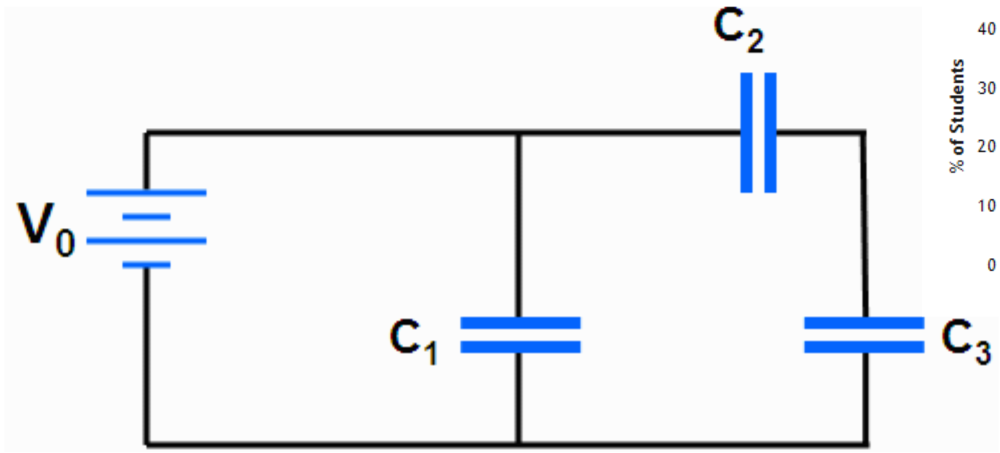


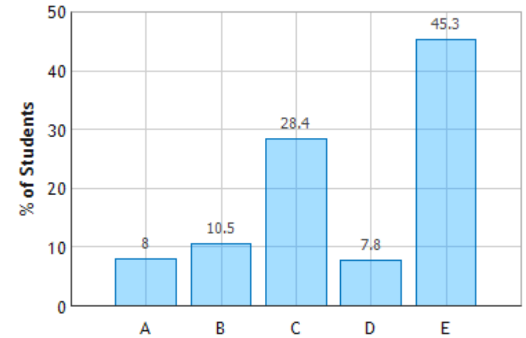
Which of the following is NOT necessarily true:

A) $V_0 = V_1$
B) $C_{total} > C_1$
C) $V_2 = V_3$
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.*** $Q_1 < Q_2 = Q_3$

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

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

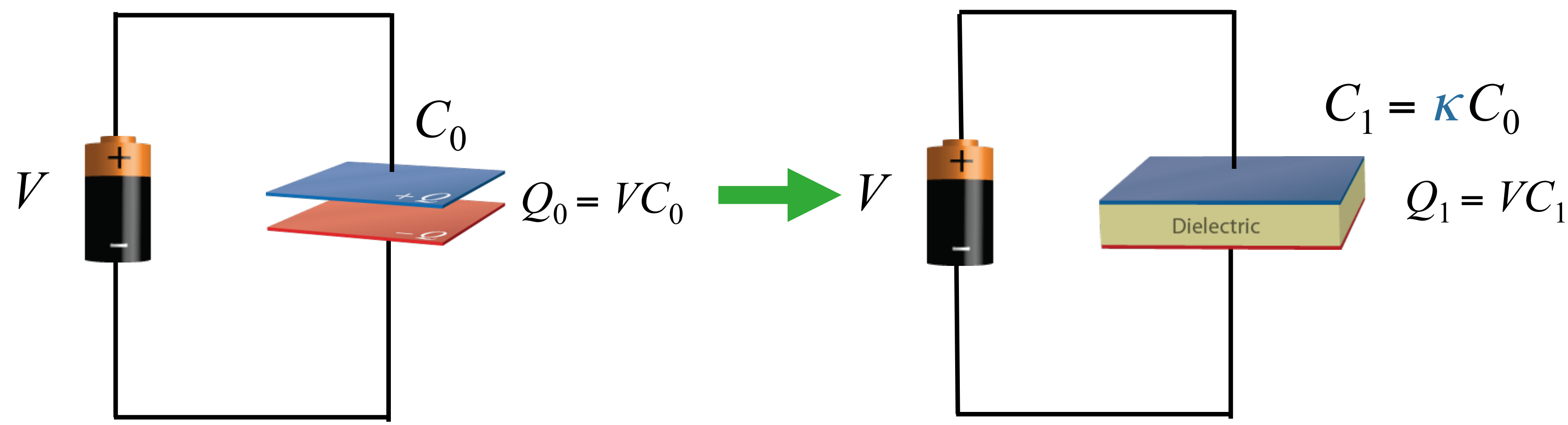
$$\frac{1}{C_{23}} = \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{2C_1} + \frac{1}{3C_1} = \frac{5}{6C_1}$$

$$C_{23} = \frac{6}{5} C_1$$

$$Q_1 = C_1 V_0$$

$$Q_{23} = Q_2 = Q_3 = C_{23} V_0 = \frac{6}{5} C_1 V_0$$

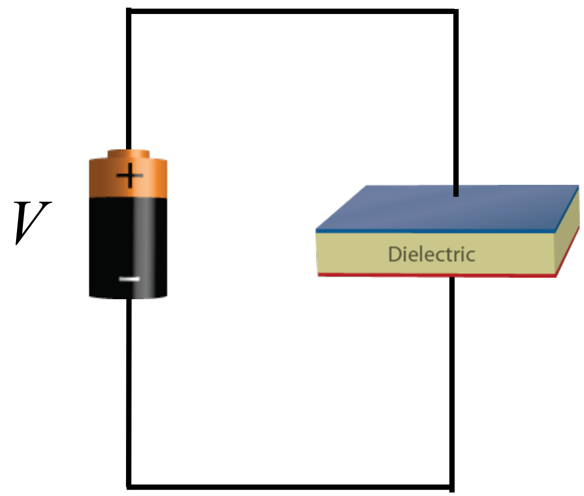
Dielectrics



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

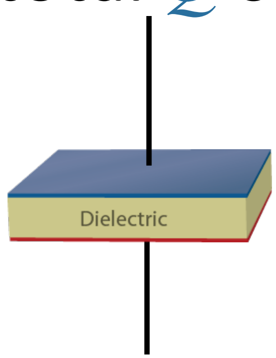
Messing with Capacitors

If connected to a battery V stays constant



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

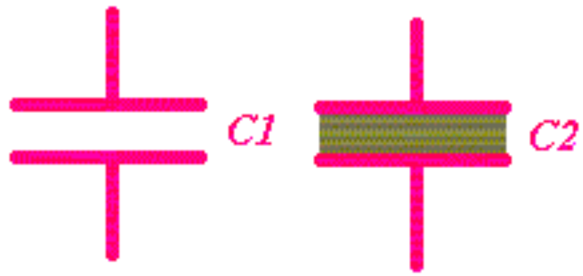
If isolated then total Q stays constant



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

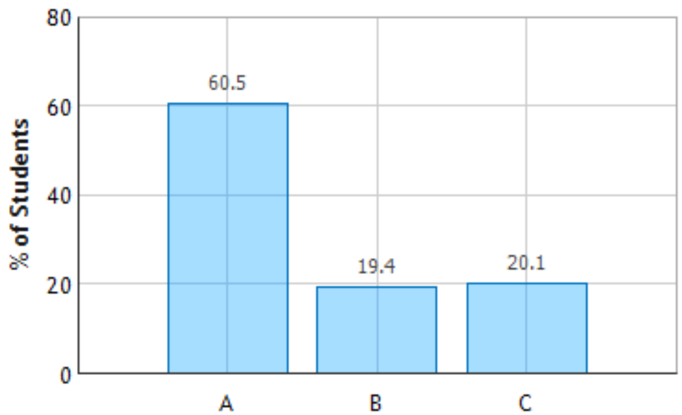
CheckPoint 4a

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 $V_1 < V_2$



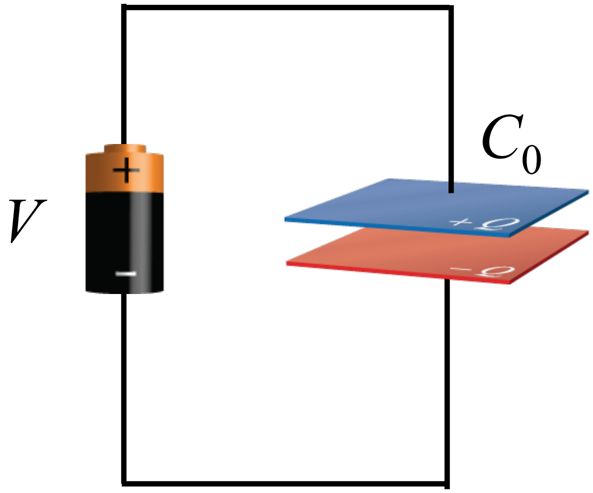
"Both have the same charge but 2 has a bigger capacitance so it has a smaller voltage."

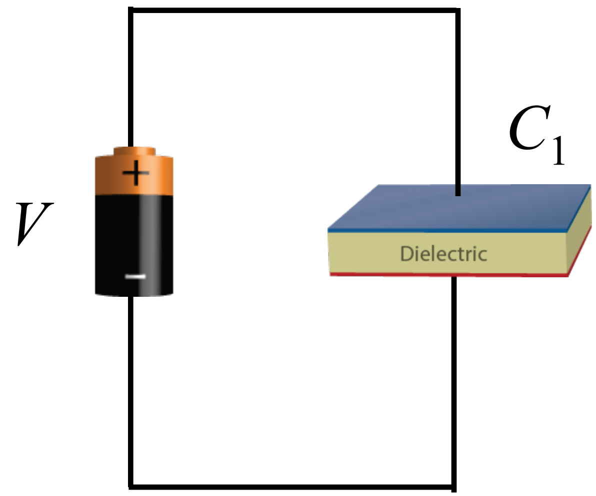
"Voltage depends on charge not dielectric"

"C=Q/V. Q stays the same while C increases due to the dielectric, so in order to adjust for this increase, we need to decrease the V."

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) $U_1 > U_0$

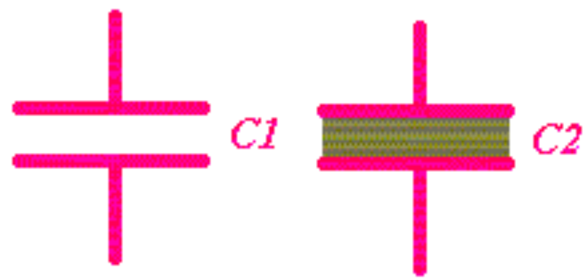
Compare using $U = {}^1/_2 CV^2$

$$U_1/U_0 = \kappa$$

→ 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



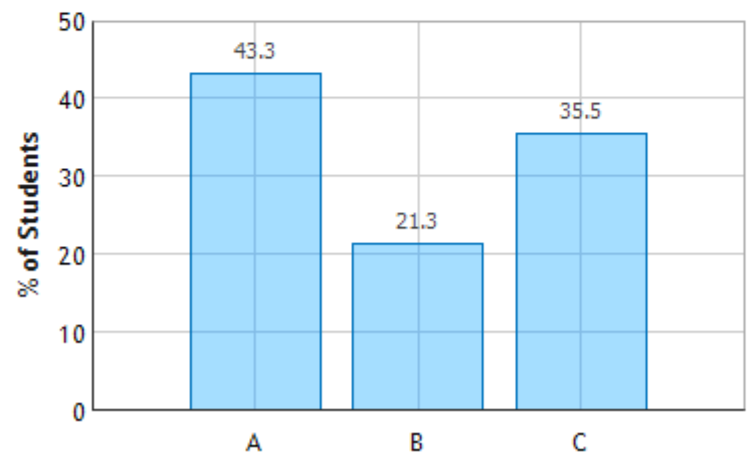
Compare the potential energy stored by the two capacitors.

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

The potential energy is directly related to the electric field. The lower the field, the lower the potential energy.

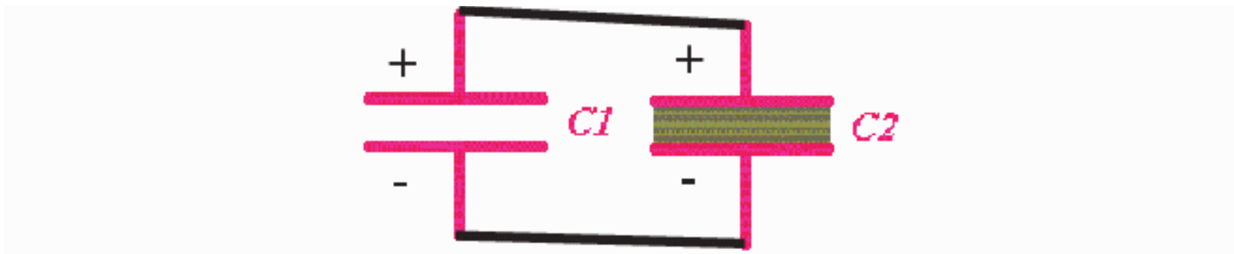
The potential energy depends on the charge only

C=Q/V Q remains the same while V reduced, so C increase. since U=0.5CV^2, U is increased.



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?**

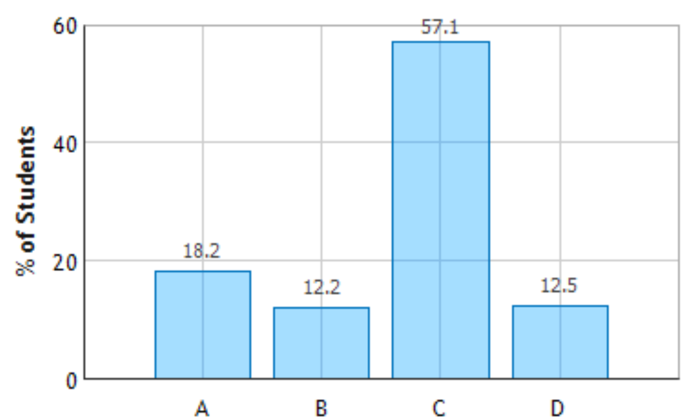


A. The charges will flow so that the charge on C_1 will become equal to the charge on C_2.
B. The charges will flow so that the energy stored in C_1 will become equal to the energy stored in C_2.
C. The charges will flow so that the potential difference across C_1 will become the same as the potential difference across C_2.
D. No charges will flow. The charge on the capacitors will remain what it was before they were connected.

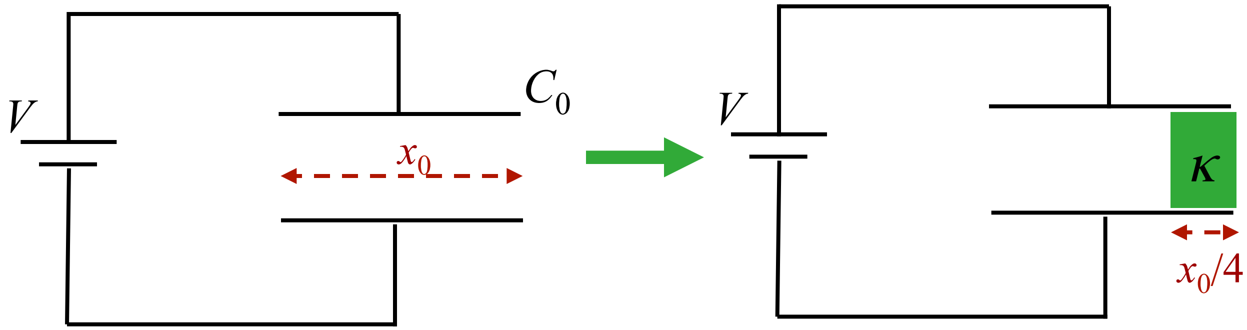
V must be the same !!

Q: $\frac{Q_1}{C_1} = \frac{Q_2}{C_2}$ → $Q_1 = \frac{C_1}{C_2} Q_2$

U: $U_1 = \frac{1}{2} C_1 V^2$, $U_2 = \frac{1}{2} C_2 V^2$ → $U_1 = \frac{C_1}{C_2} U_2$



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:

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

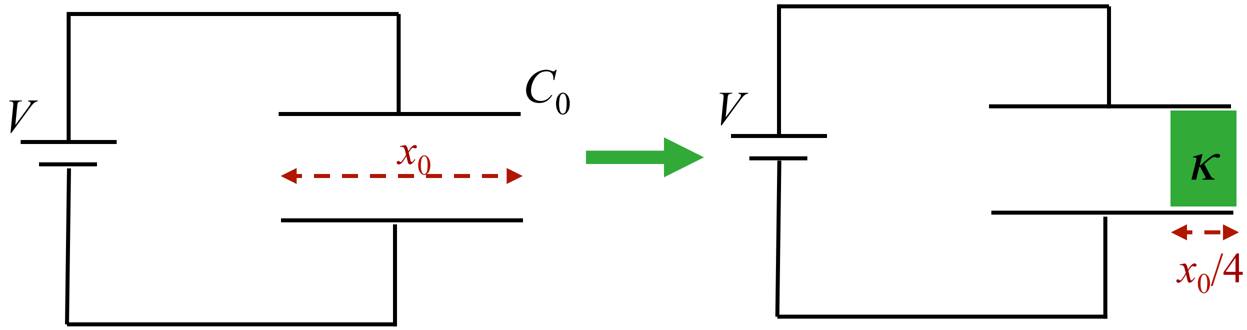
What changes when the dielectric added?

A) Only C B) only Q C) only V D) C 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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What is Q_f, the final charge on the capacitor?

Strategic Analysis:

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

To calculate C, let's first look at:

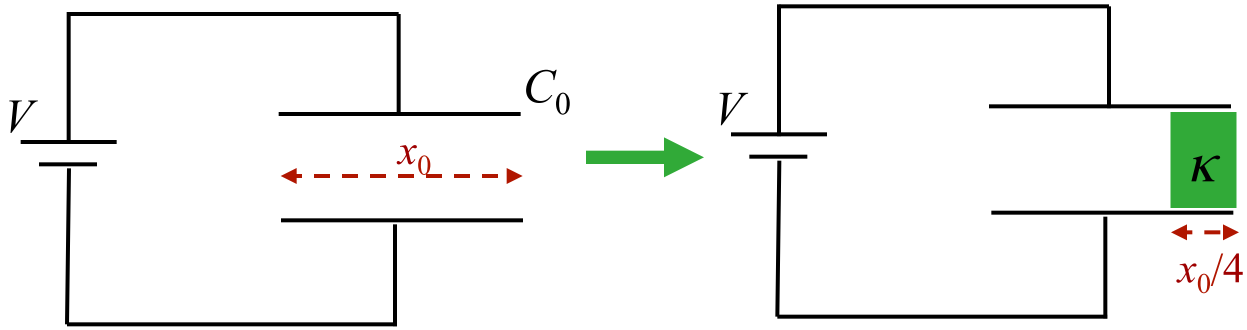
A) $V_{left} < V_{right}$

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

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

The conducting plate is an equipotential !

Calculation



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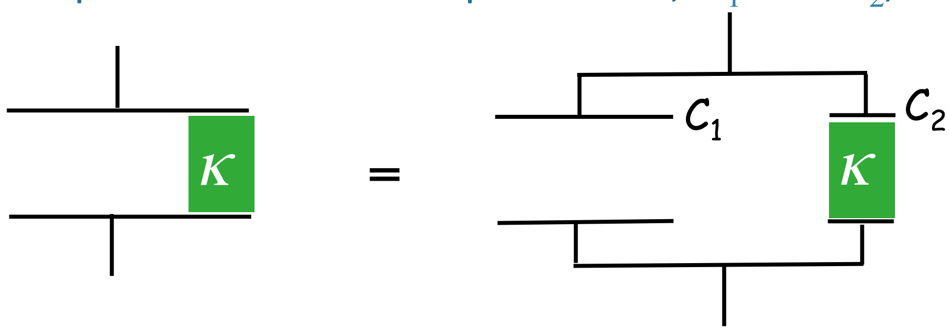
What is Q_f, the final charge on the capacitor?

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



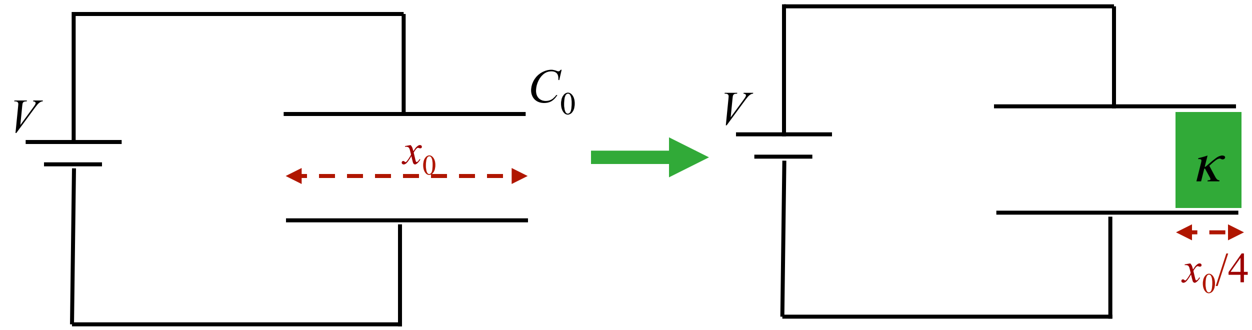
What is C_1 ?

A) $C_1 = C_0$ **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: $C = \varepsilon_0 A/d$

$$A = {}^3/_4 A_0, \quad d = d_0 \;\rightarrow\; C_1 = {}^3/_4(\varepsilon_0 A_0/d_0) \;\rightarrow\; C_1 = {}^3/_4 C_0$$

Calculation



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

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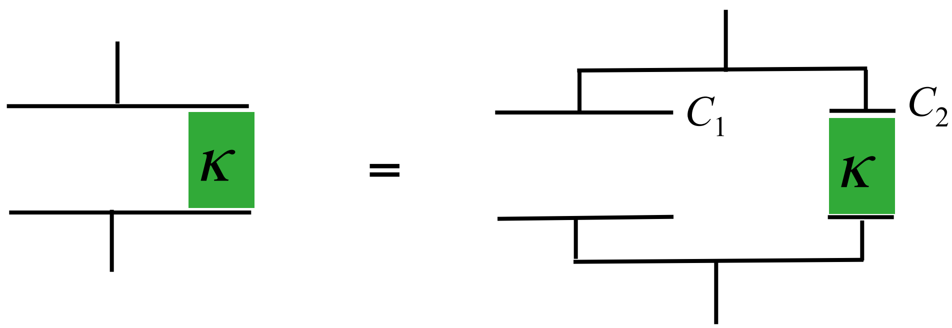
What is Q_f, the final charge on the capacitor?



$C_1 = {}^3\!/_4 C_0$

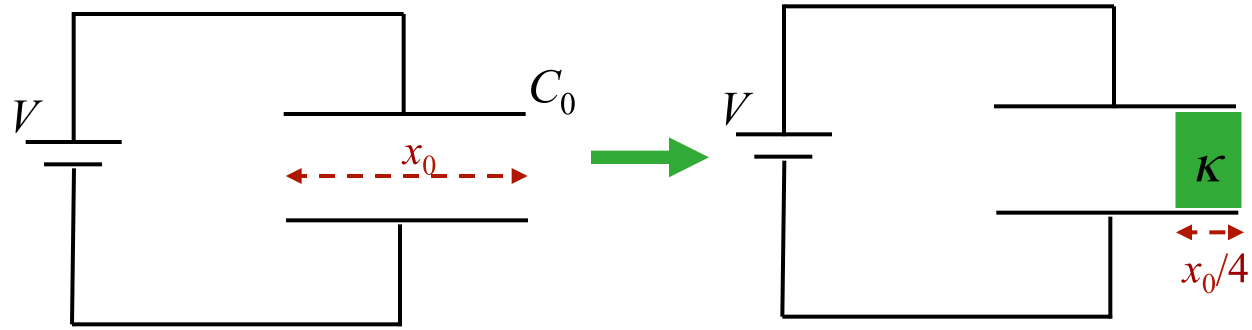
What is C_2 ?

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

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

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

Calculation



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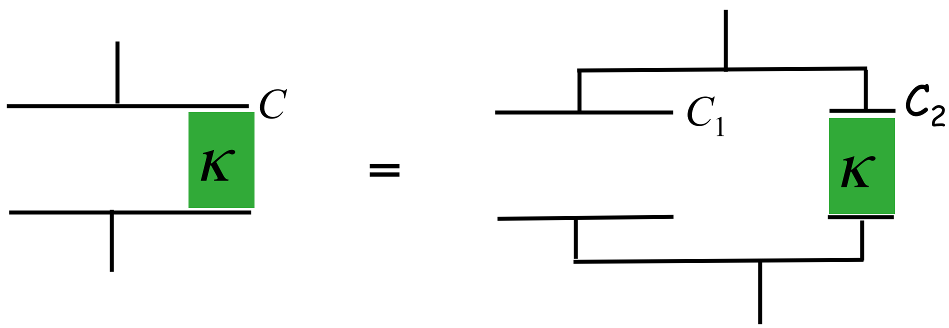


$C_1 = {}^3/_4 C_0$ $\qquad$ $C_2 = {}^1/_4\, \kappa C_0$

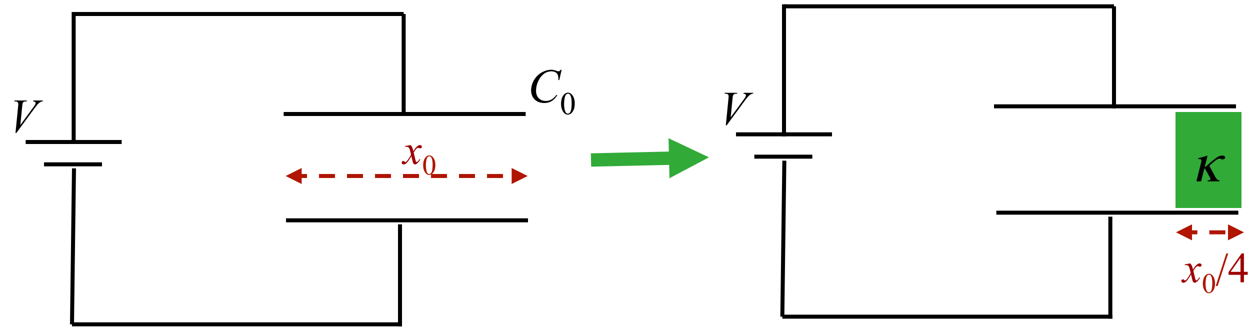
What is C?

A) $C = C_1 + C_2$ $\qquad$ B) $C = C_1 + \kappa C_2$ $\qquad$ 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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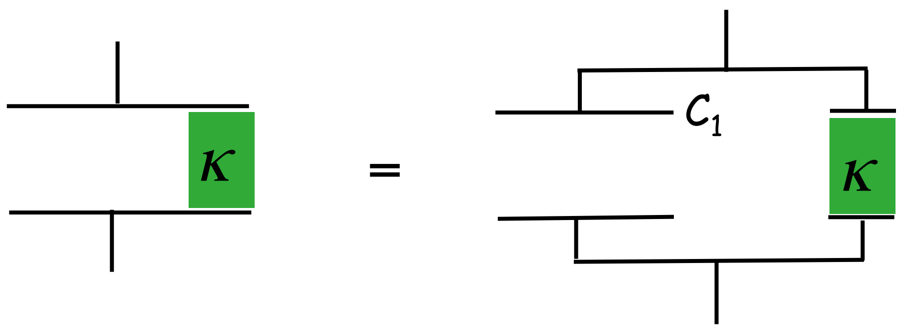

$C_1 = {}^3/_4 C_0$ $C_2 = {}^1/_4\, \kappa C_0$

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

What is Q?

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

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