Class 08: Outline

Hour 1:

Last Time: Conductors

Expt. 3: Faraday Ice Pail

Hour 2:

Capacitors & Dielectrics

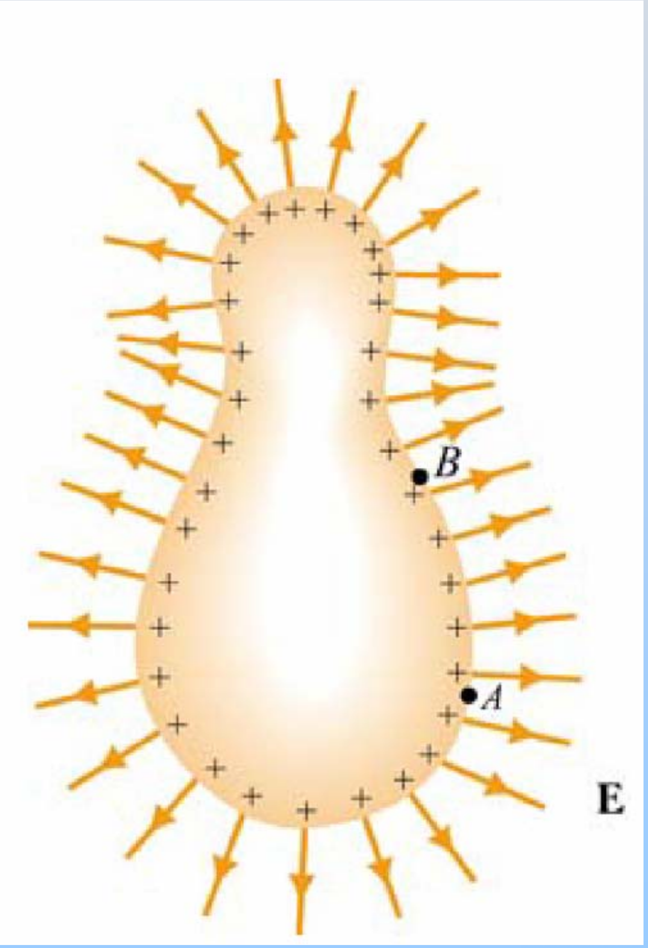
Last Time:
Conductors

Conductors in Equilibrium

Conductors are equipotential objects:

1) E = 0 inside
2) Net charge inside is 0
3) E perpendicular to surface
4) Excess charge on surface

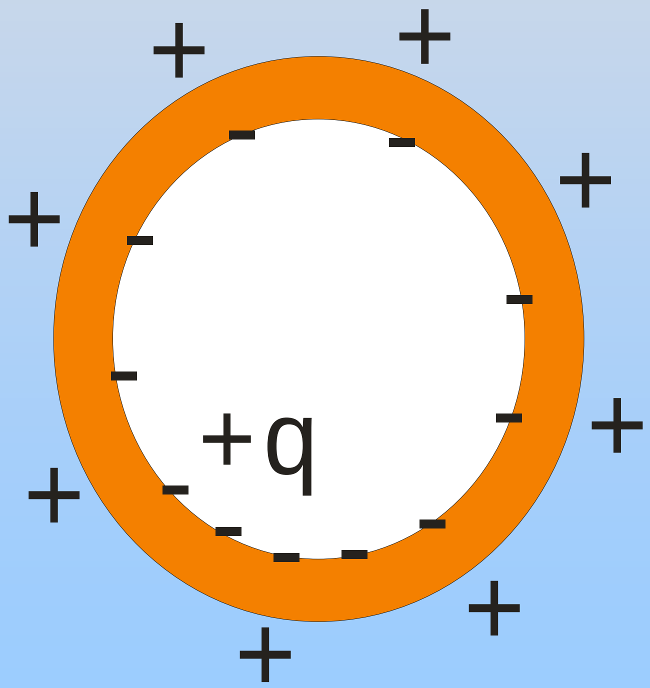
$$E = \sigma / \varepsilon_0$$

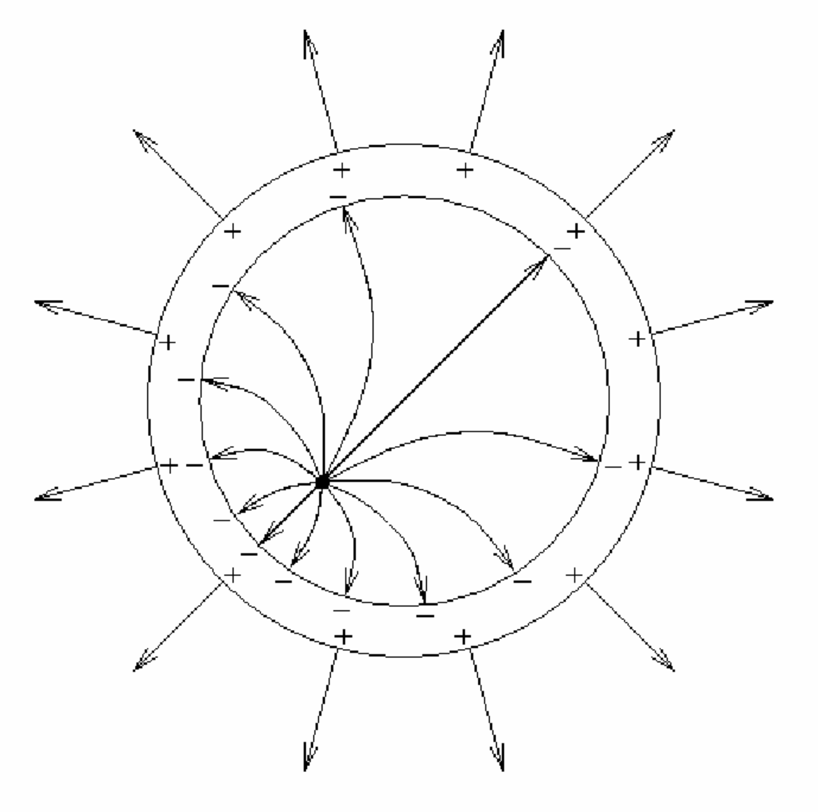


Conductors as Shields

Hollow Conductors

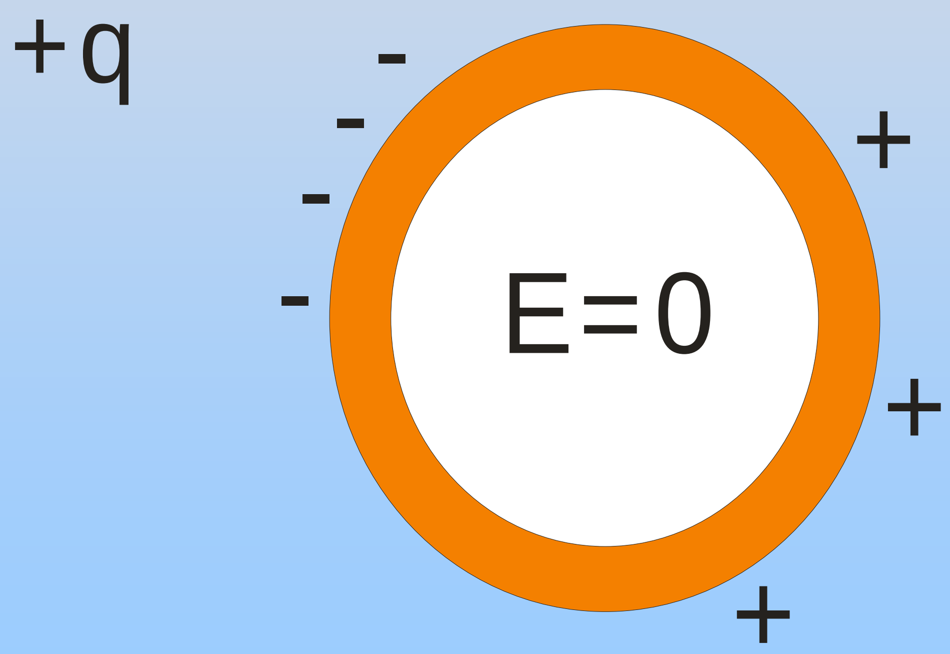
Charge placed INSIDE induces balancing charge INSIDE



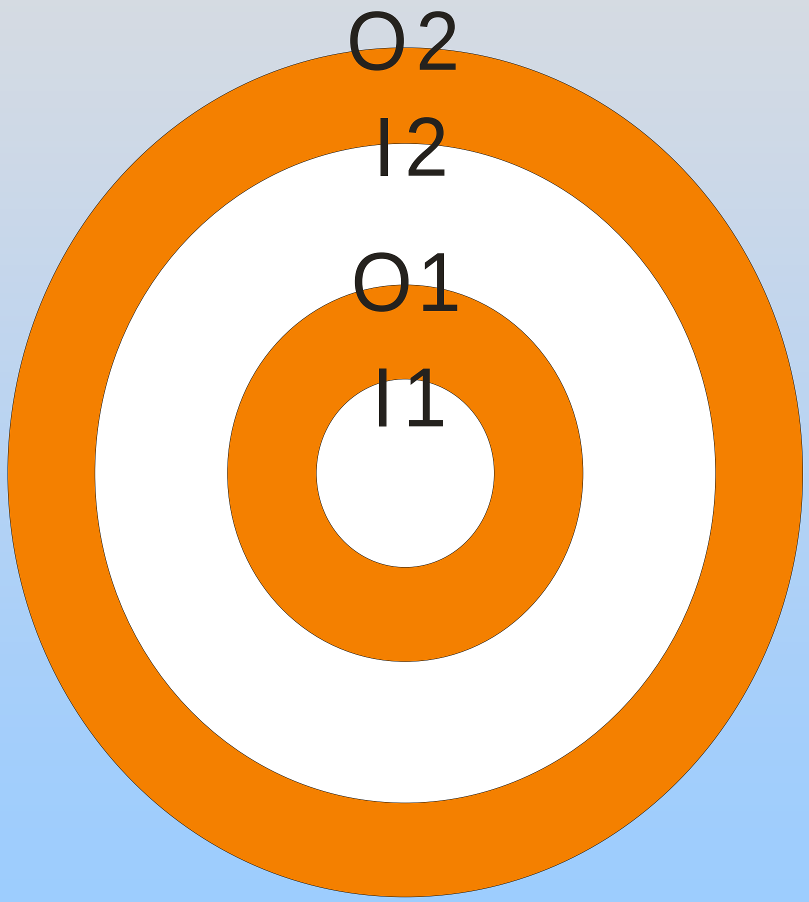


Hollow Conductors

Charge placed OUTSIDE induces charge separation on OUTSIDE



PRS Setup

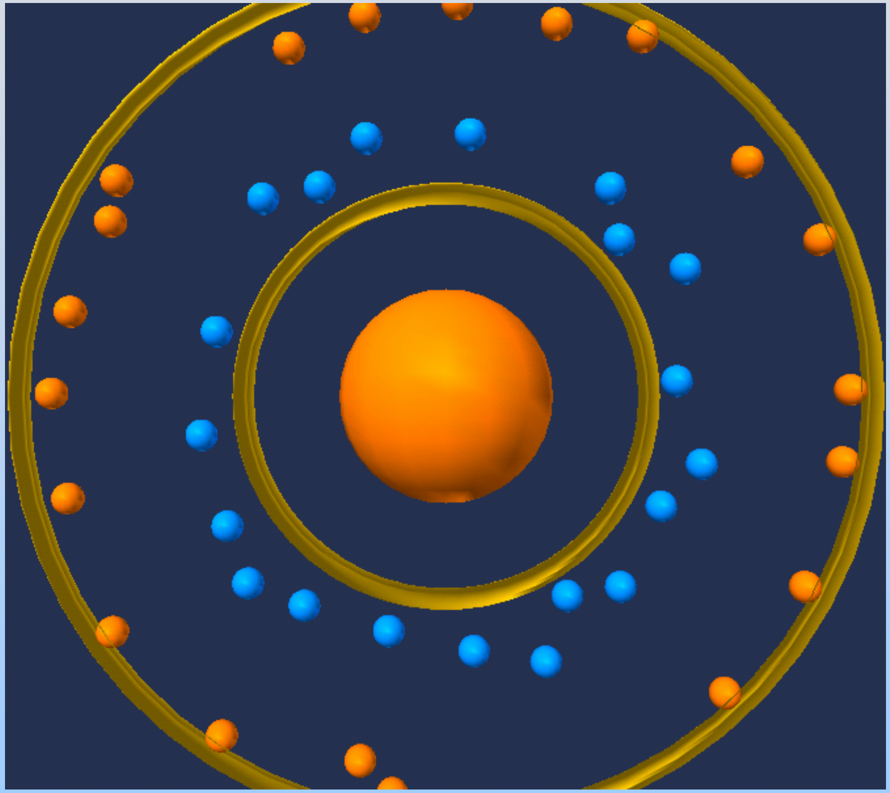


What happens if we put Q in the center?

PRS Questions: Point Charge Inside Conductor

Demonstration: Conductive Shielding

Visualization: Inductive Charging

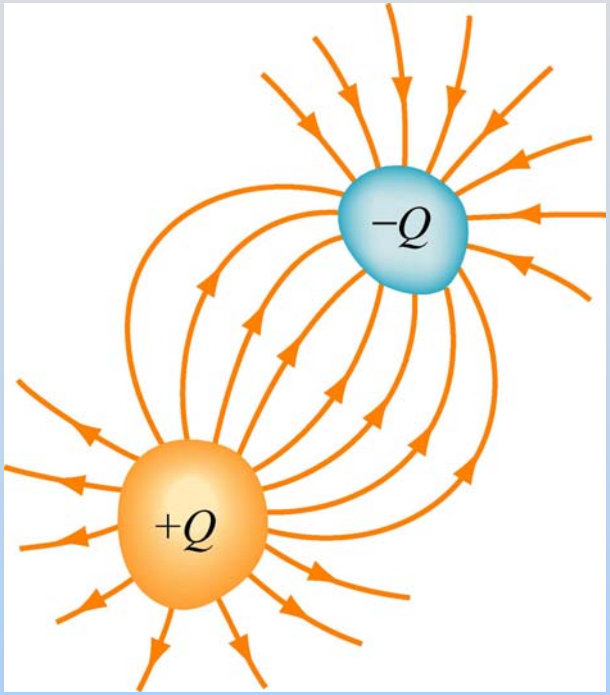


http://ocw.mit.edu/ans7870/8/8.02T/f04/visualizations/electrostatics/40-chargebyinduction/40-chargebyinduction.html

Experiment 3: Faraday Ice Pail

Last Time:
Capacitors

Capacitors: Store Electric Energy



$$C = \frac{Q}{|\Delta V|}$$

To calculate:

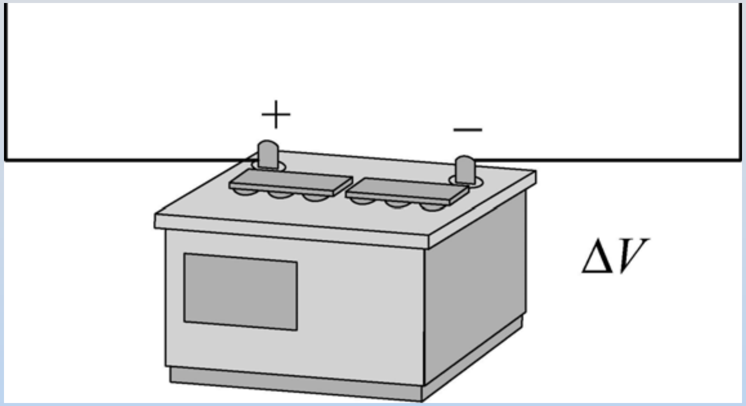
1) Put on arbitrary ±Q
2) Calculate E
3) Calculate ΔV

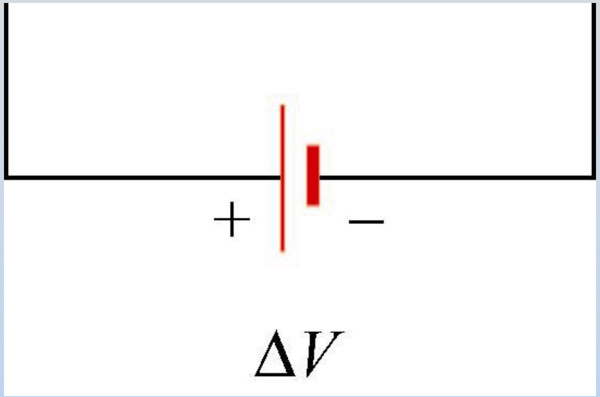
Parallel Plate Capacitor:

$$C = \frac{\varepsilon_0 A}{d}$$

Batteries & Elementary Circuits

Ideal Battery



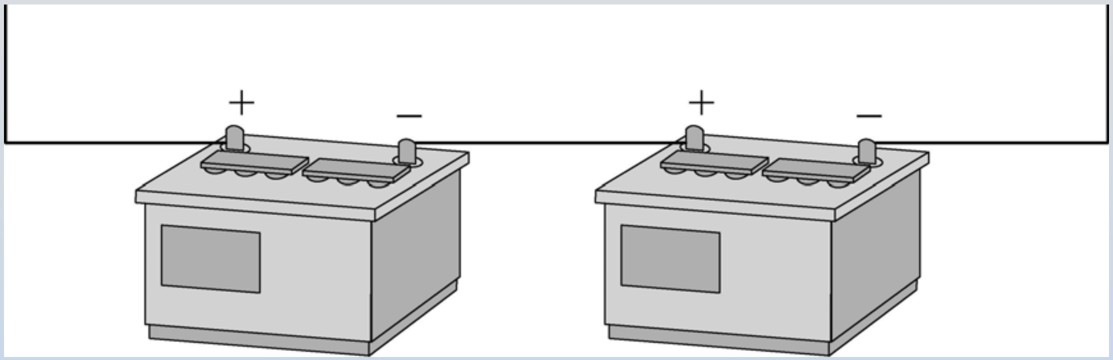


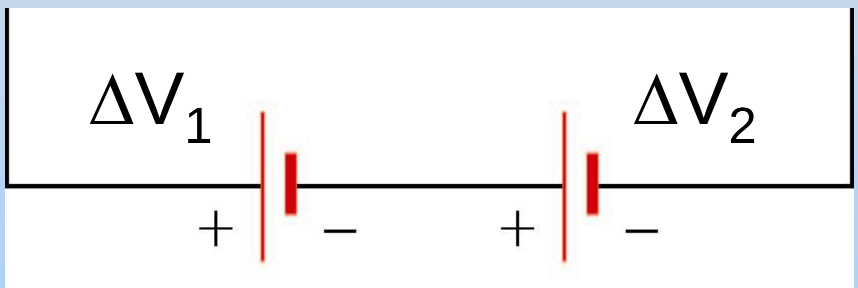
Fixes potential difference between its terminals

Sources as much charge as necessary to do so

Think: Makes a mountain

Batteries in Series

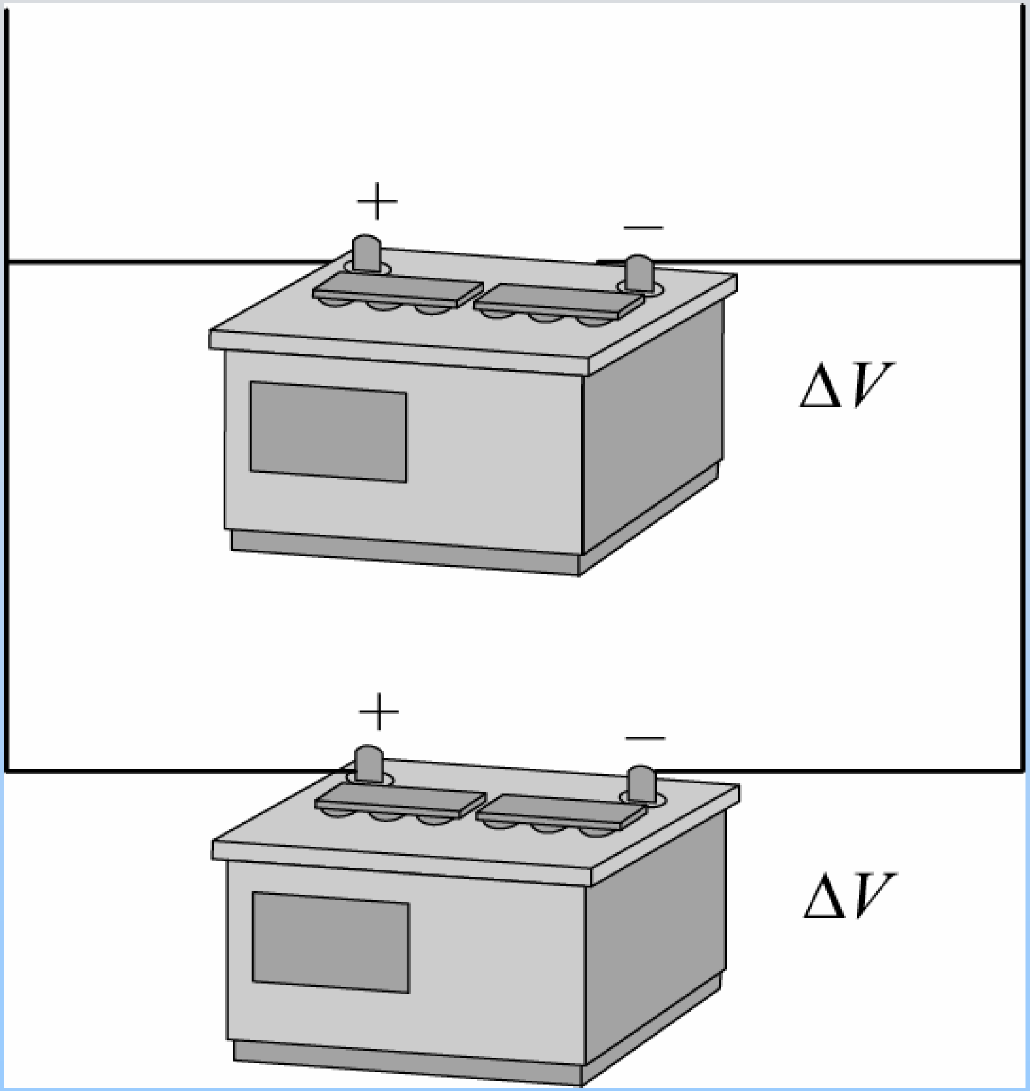




Net voltage change is $\Delta V = \Delta V_1 + \Delta V_2$

Think: Two Mountains Stacked

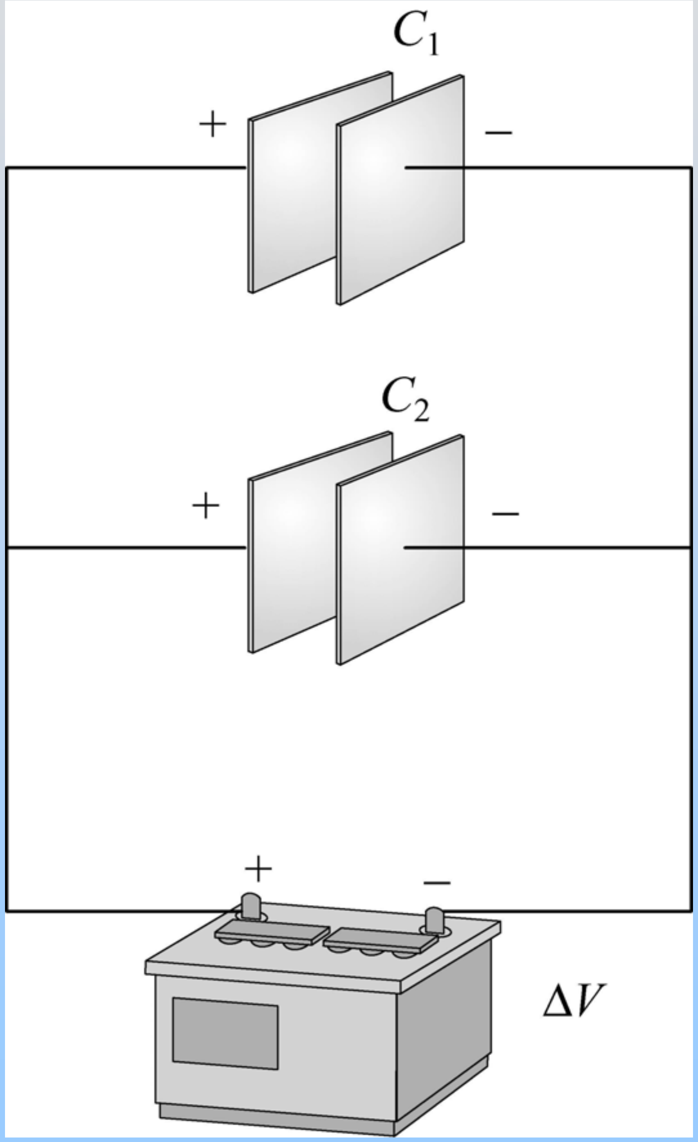
Batteries in Parallel



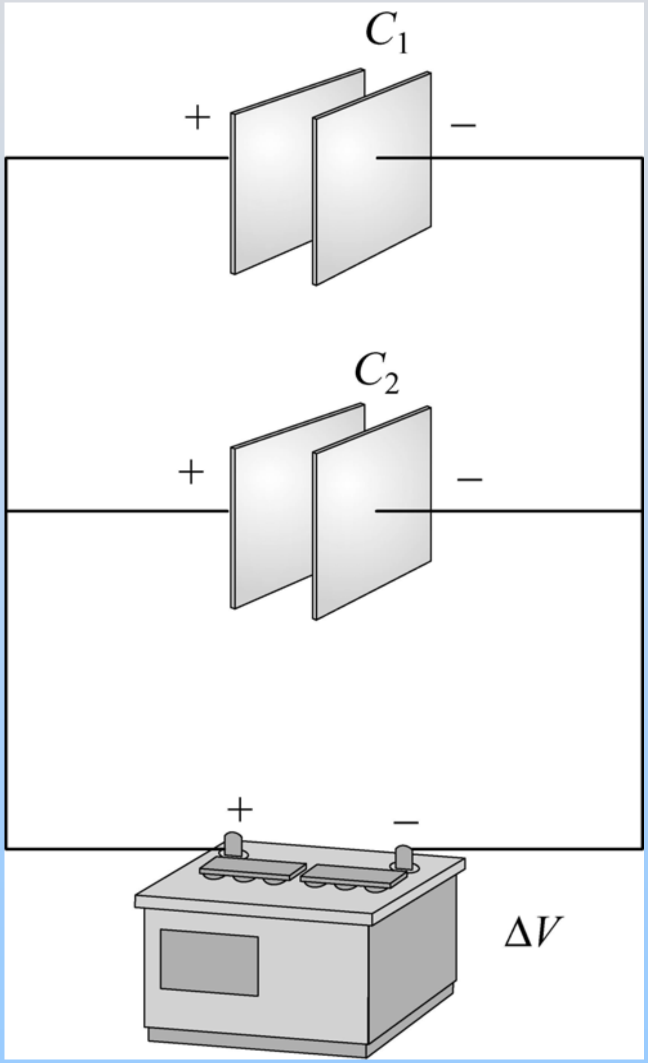
Net voltage still ΔV

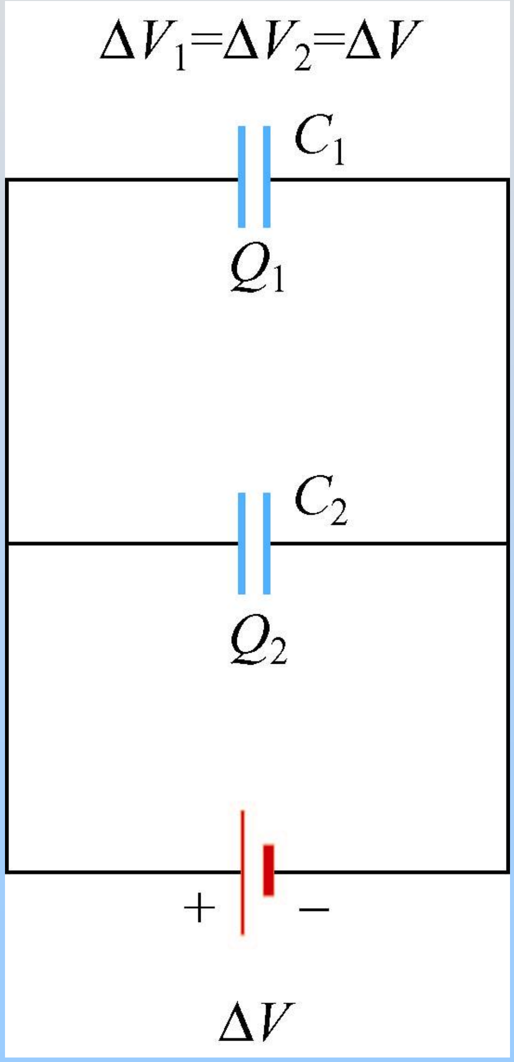
Don’t do this!

Capacitors in Parallel



Capacitors in Parallel

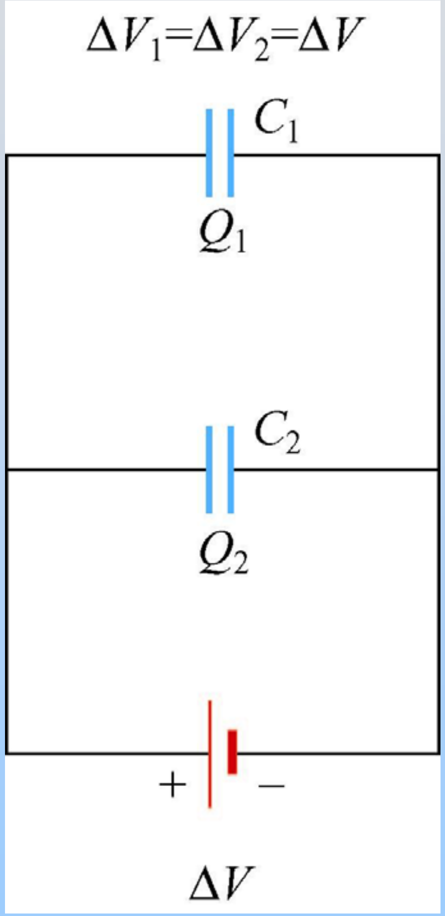




Same potential!

$$C_1 = \frac{Q_1}{\Delta V},\ C_2 = \frac{Q_2}{\Delta V}$$

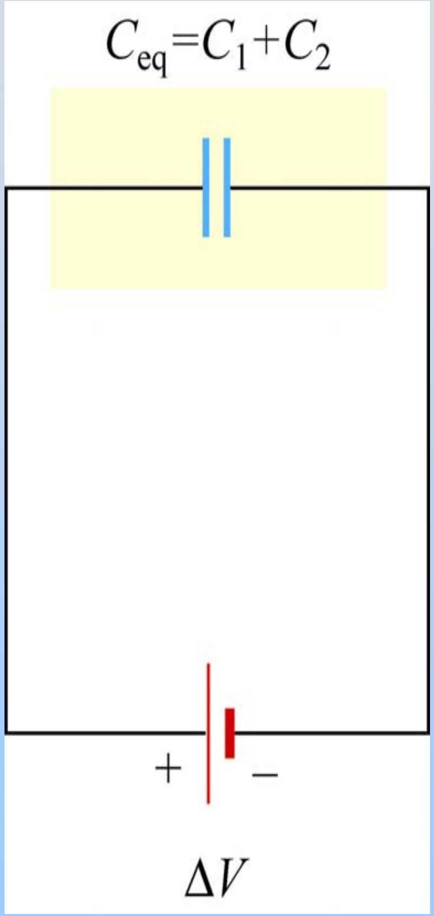
Equivalent Capacitance



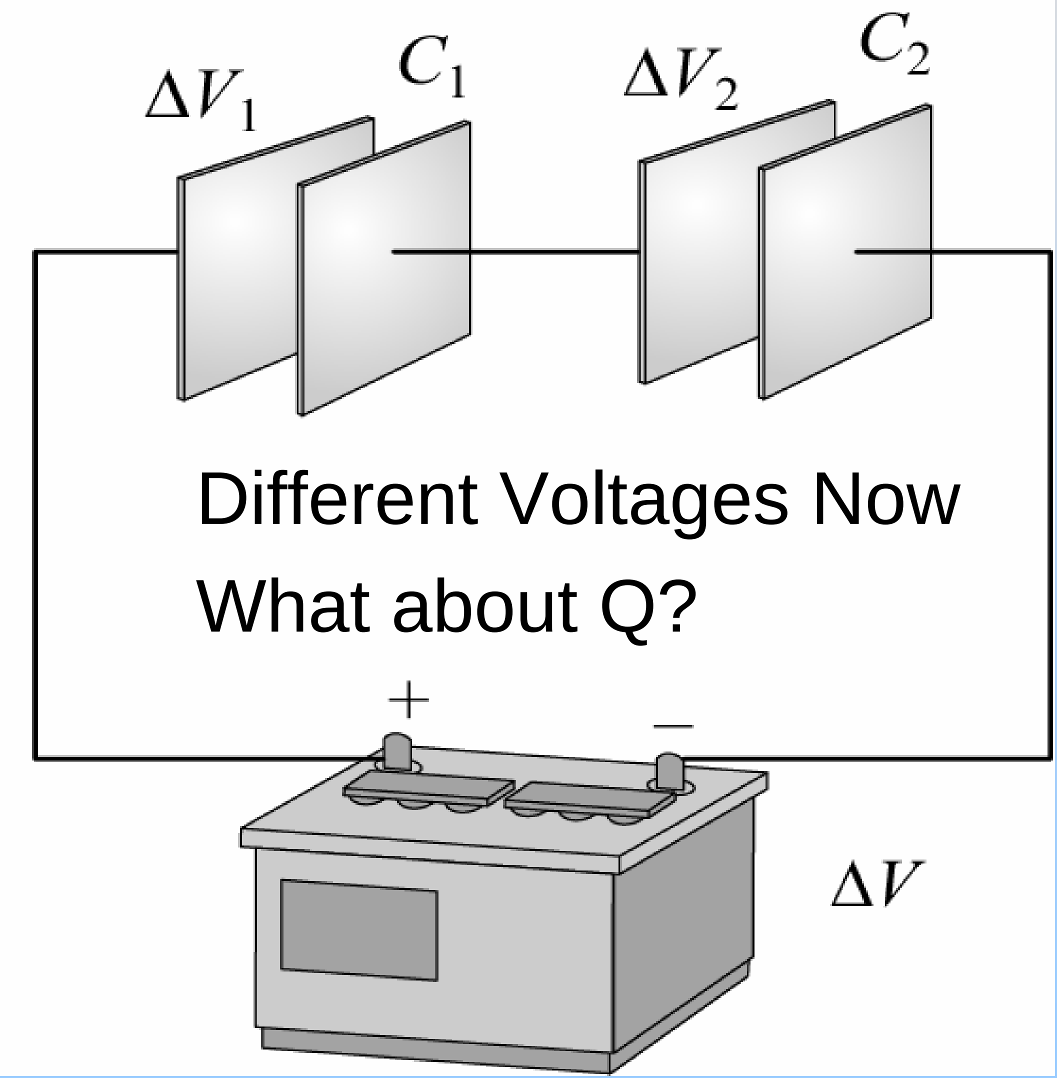
?

$$Q = Q_1 + Q_2 = C_1 \Delta V + C_2 \Delta V$$
$$= \left(C_1 + C_2 \right) \Delta V$$

$$C_{eq} = \frac{Q}{\Delta V} = C_1 + C_2$$



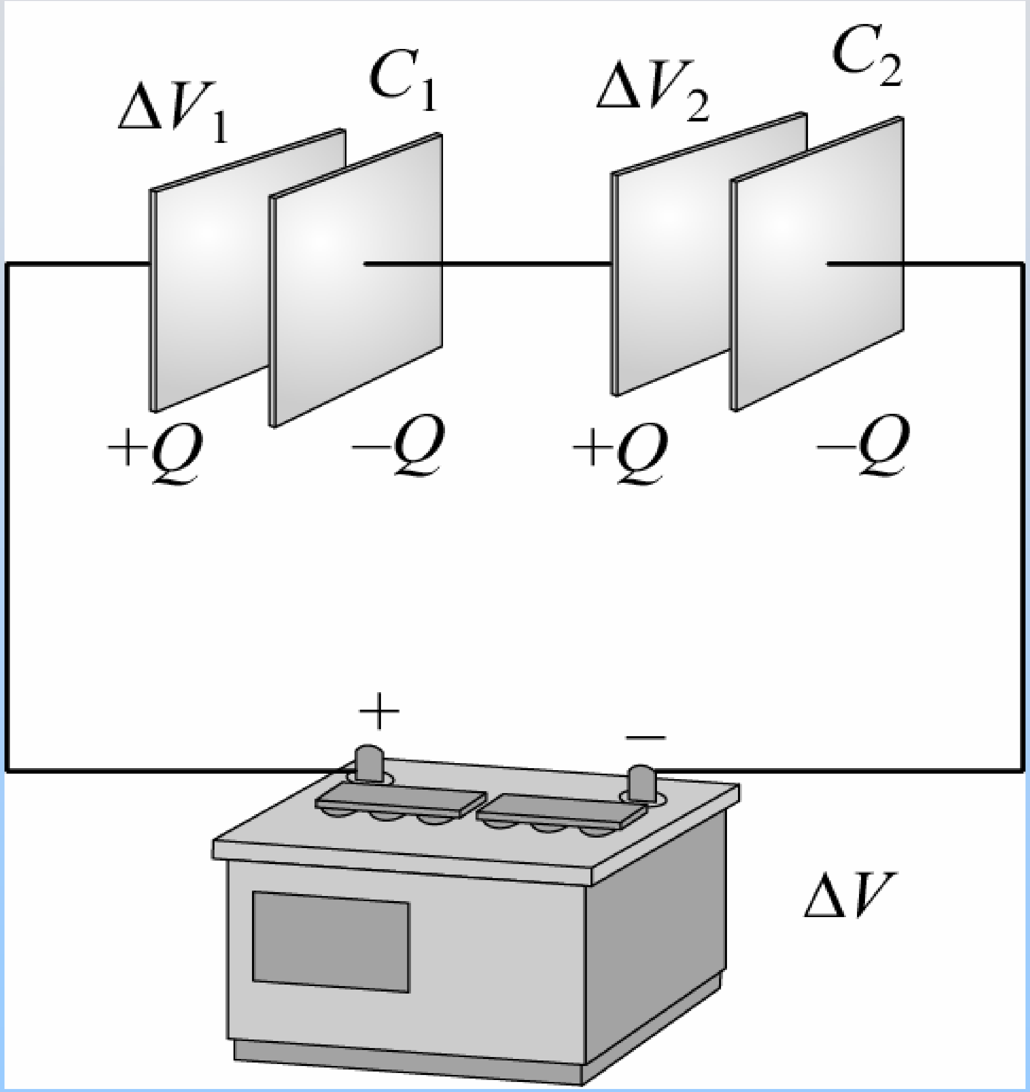
Capacitors in Series



Different Voltages Now

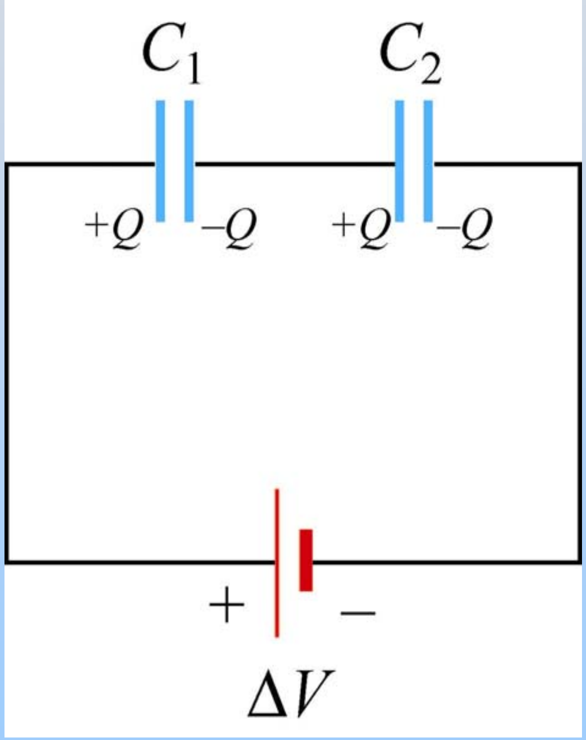
What about Q?

Capacitors in Series



Equivalent Capacitance

$$\Delta V_1 = \frac{Q}{C_1}, \;\; \Delta V_2 = \frac{Q}{C_2}$$

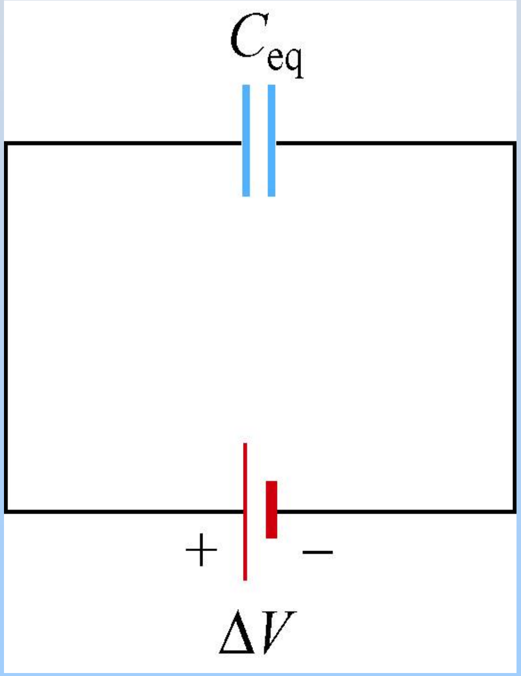


$$\Delta V = \Delta V_1 + \Delta V_2$$

(voltage adds in series)

$$\Delta V = \frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

$$\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}}$$



PRS Question:
Capacitors in Series and Parallel

Dielectrics

Demonstration: Dielectric in Capacitor

Dielectrics

A dielectric is a non-conductor or insulator

Examples: rubber, glass, waxed paper

When placed in a charged capacitor, the dielectric reduces the potential difference between the two plates

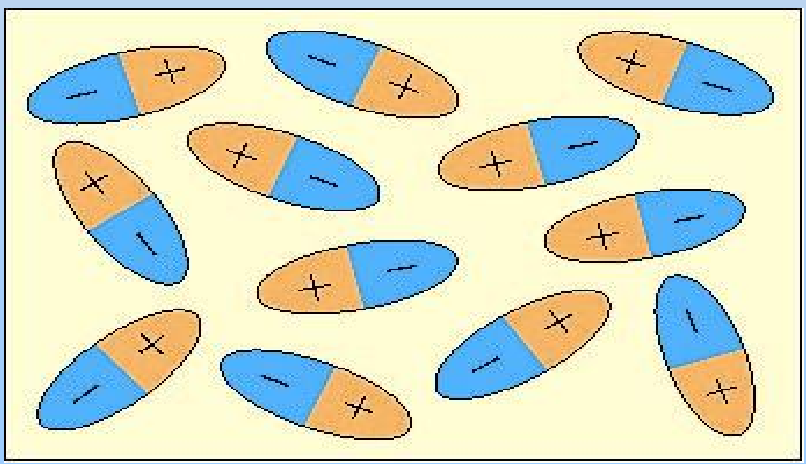
HOW???

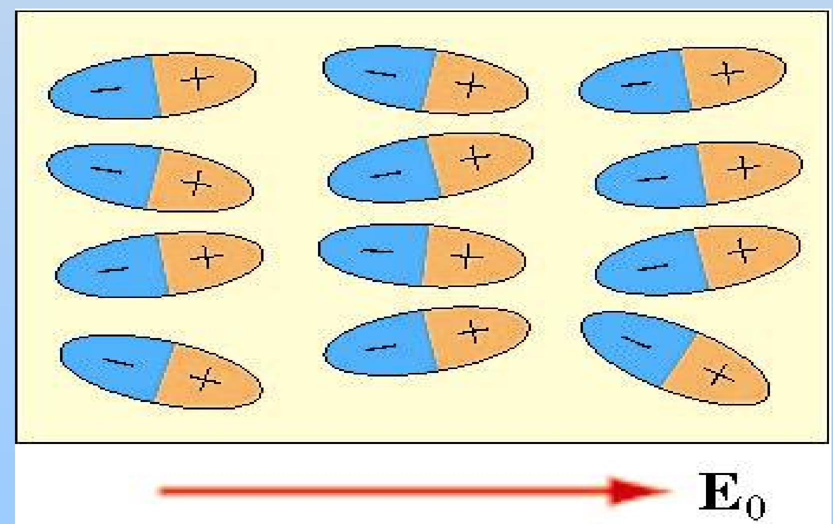
Molecular View of Dielectrics

Polar Dielectrics :

Dielectrics with permanent electric dipole moments

Example: Water



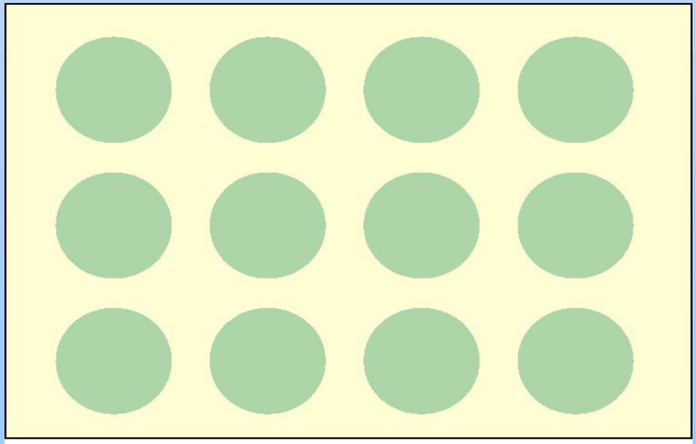


Molecular View of Dielectrics

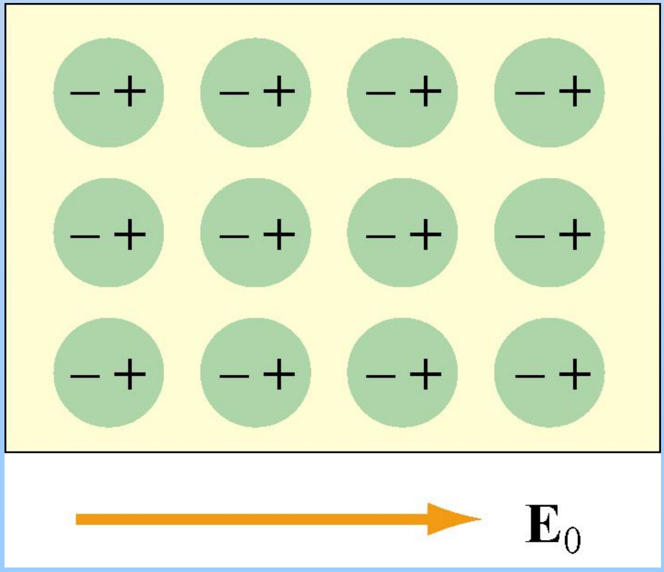
Non-Polar Dielectrics

Dielectrics with induced electric dipole moments

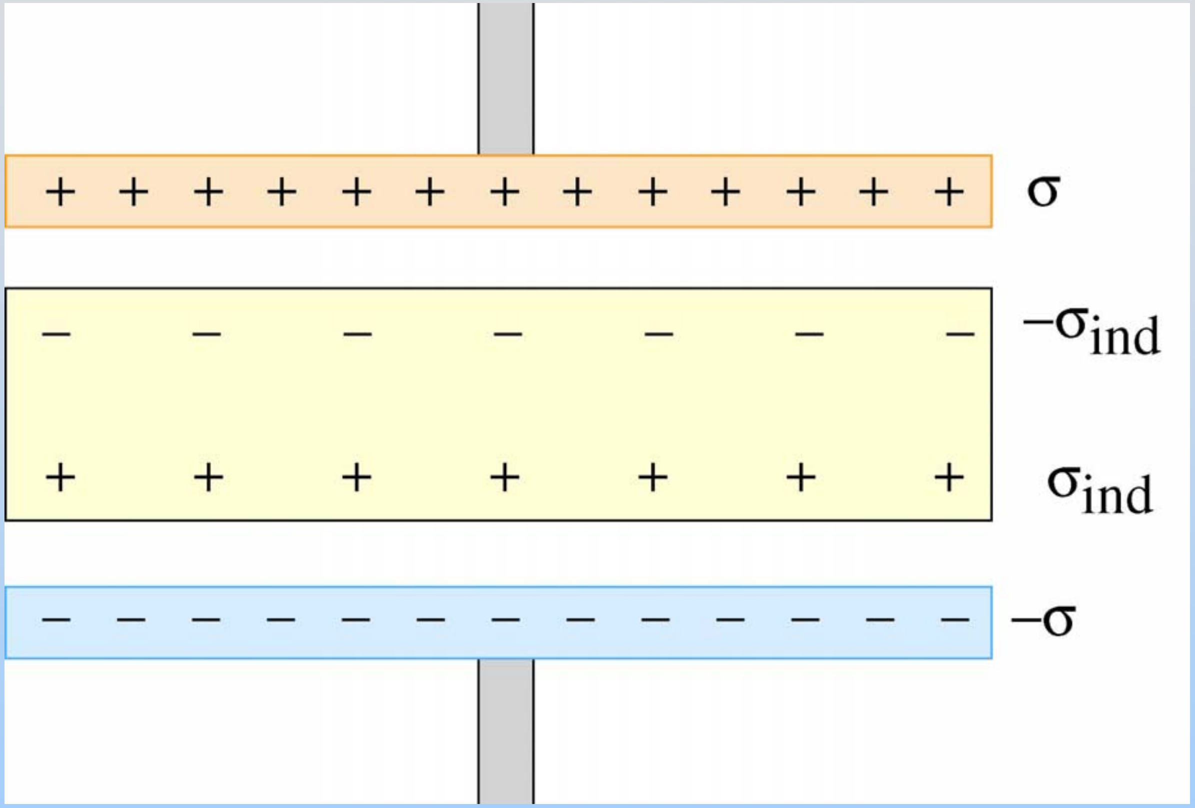
Example: CH_4



$E_0 = 0$

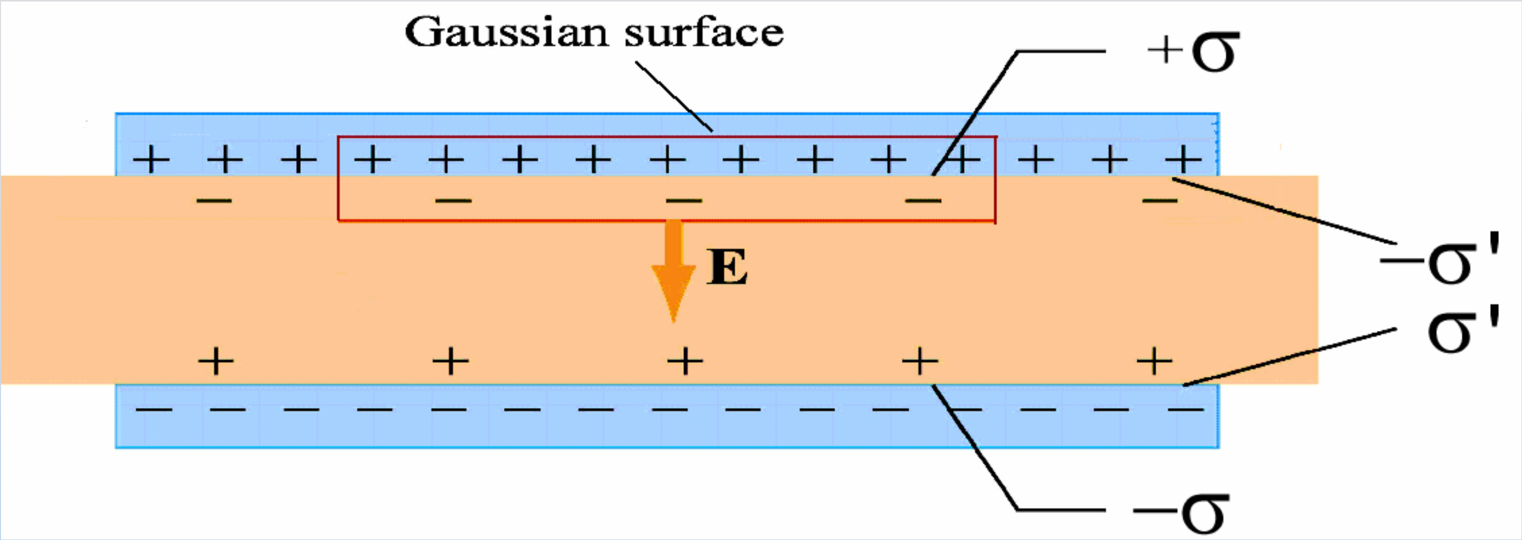


Dielectric in Capacitor



Potential difference decreases because dielectric polarization decreases Electric Field!

Gauss's Law for Dielectrics



Upon inserting dielectric, a charge density σ' is induced at its surface

$$\oiint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = EA = \frac{q_{inside}}{\varepsilon_0} = \frac{(\sigma - \sigma')A}{\varepsilon_0}$$

$$\boxed{E = \frac{\sigma - \sigma'}{\varepsilon_0}}$$

What is σ'?

Dielectric Constant κ

Dielectric *weakens* original field by a factor κ

$$E = \frac{\sigma - \sigma'}{\varepsilon_0} \equiv \frac{E_0}{\kappa} = \frac{\sigma}{\kappa\varepsilon_0} \quad \Rightarrow \quad \boxed{\sigma' = \sigma\left(1 - \frac{1}{\kappa}\right)}$$

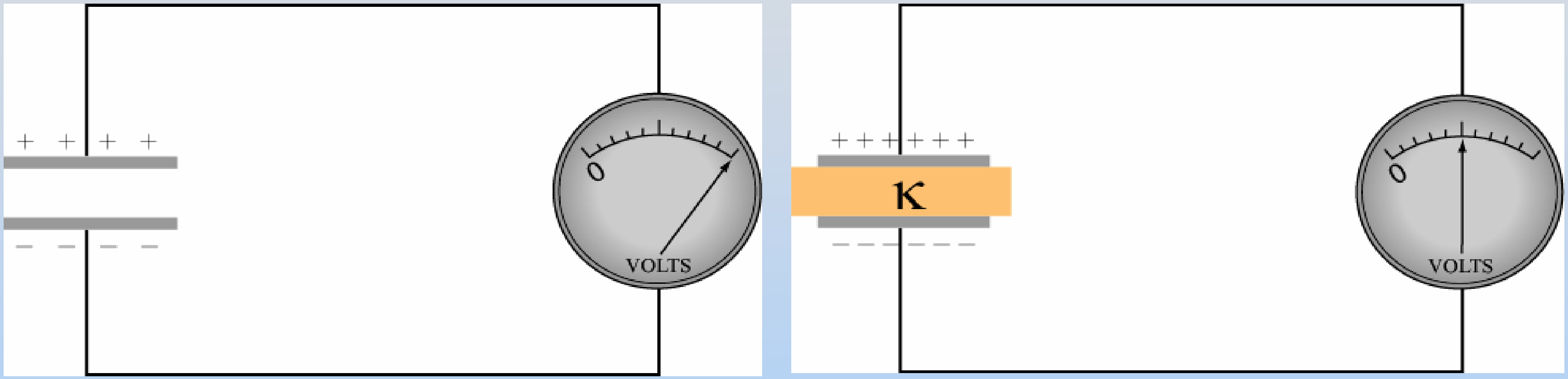
Gauss's Law with dielectrics:

$$\oiint_S \kappa \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q_{inside}^{free}}{\varepsilon_0}$$

Dielectric constants	
Vacuum	1.0
Paper	3.7
Pyrex Glass	5.6
Water	80

Dielectric in a Capacitor

Q_0= constant after battery is disconnected

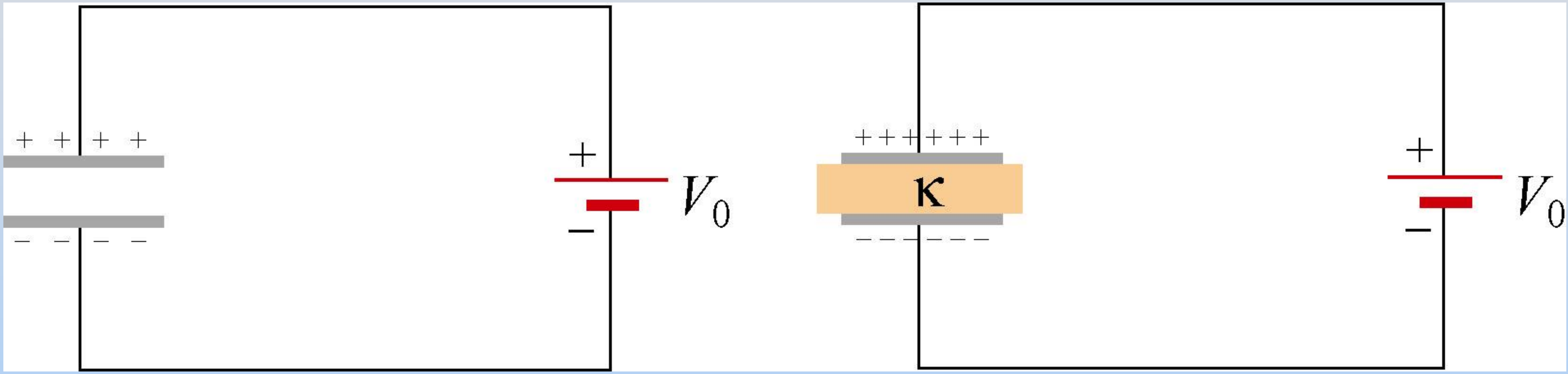


Upon inserting a dielectric: $V = \dfrac{V_0}{\kappa}$

$$C = \frac{Q}{V} = \frac{Q_0}{V_0/\kappa} = \kappa \frac{Q_0}{V_0} = \kappa C_0$$

Dielectric in a Capacitor

V_0 = constant when battery remains connected

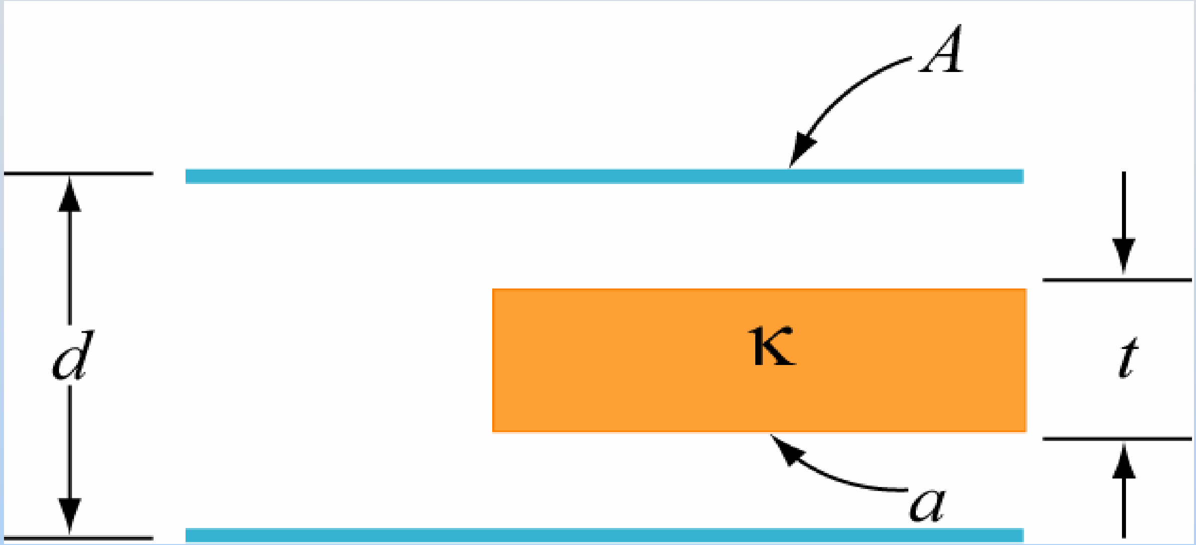


$$C = \frac{Q}{V} = \kappa C_0 = \kappa \frac{Q_0}{V_0}$$

Upon inserting a dielectric: $Q = \kappa Q_0$

PRS Questions:
Dielectric in a Capacitor

Group: Partially Filled Capacitor



What is the capacitance of this capacitor?