Class 08: Outline

Hour 1:

 Last Time: Conductors

 Expt. 3: Faraday Ice Pail

Hour 2:

 Capacitors & Dielectrics
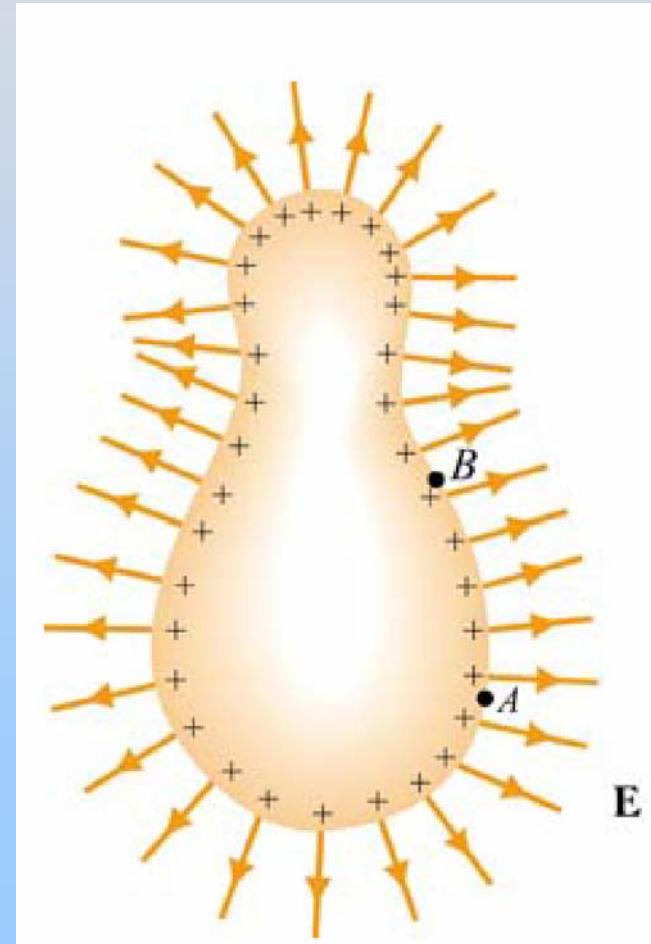
Last Time: Conductors

Conductors in Equilibrium

Conductors are equipotential objects:

1) E = 0 inside

2) Net charge inside is 0
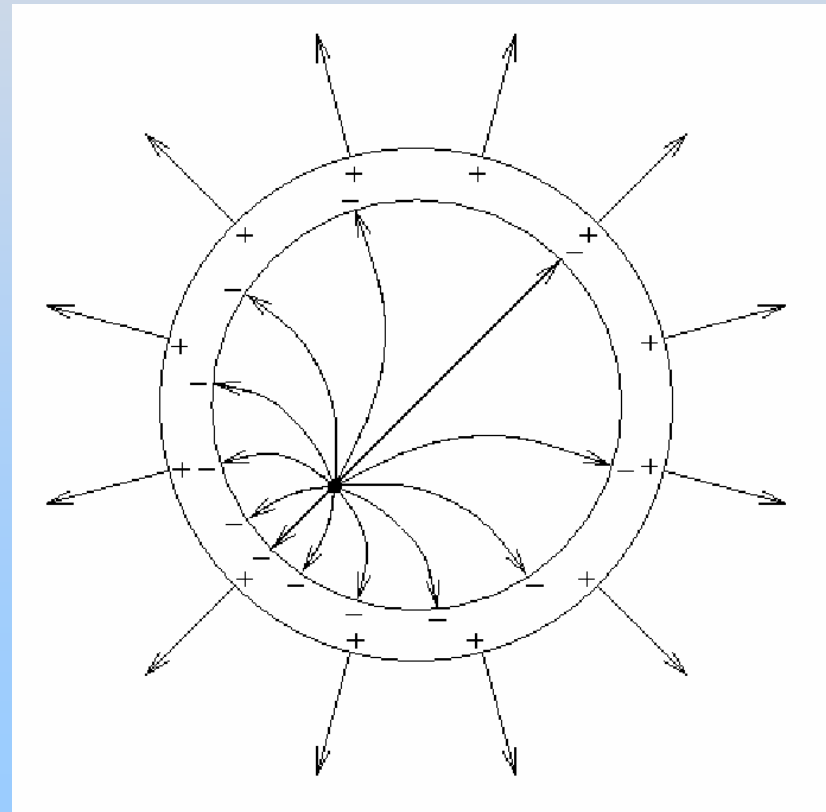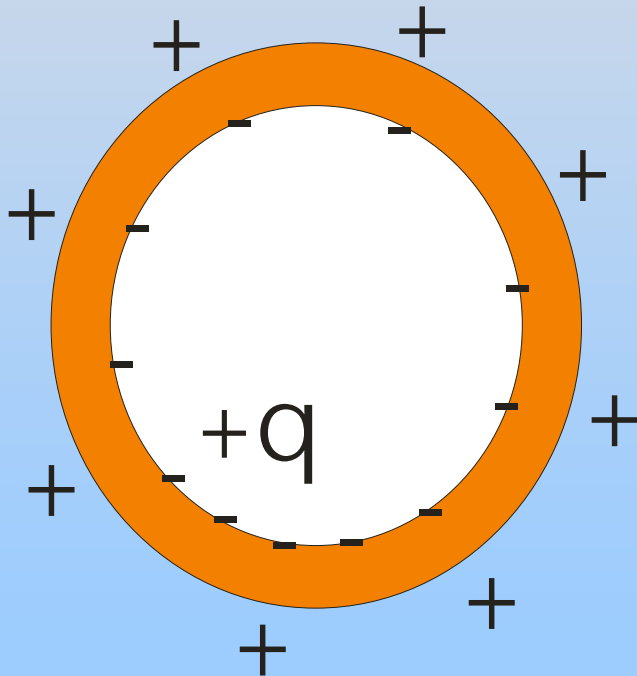
3) E perpendicular to surface

4) Excess charge on surface

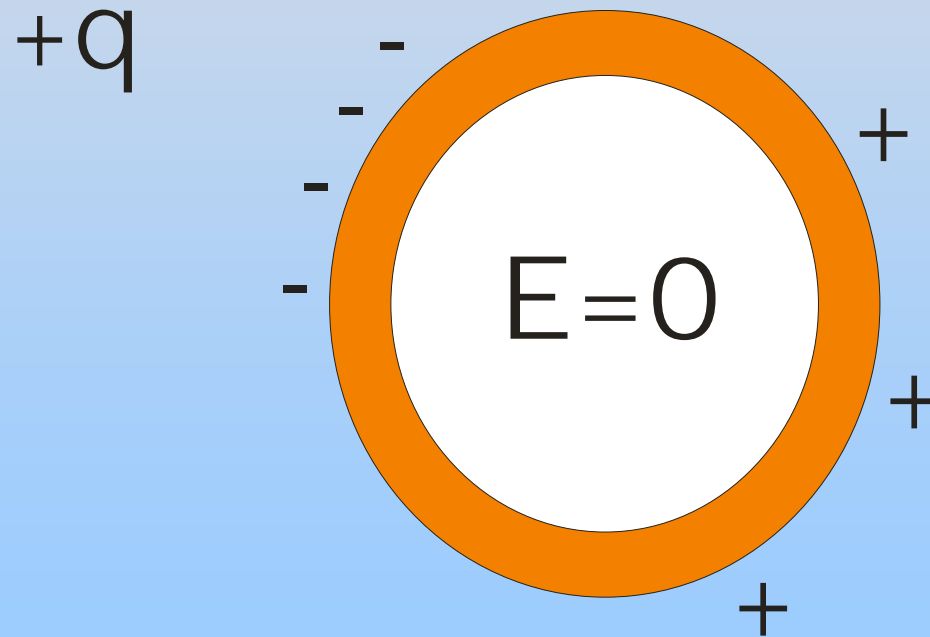$$E = \sigma / \varepsilon_0$$

Conductors as Shields

Hollow Conductors

Charge placed INSIDE induces
balancing charge INSIDE

Hollow Conductors
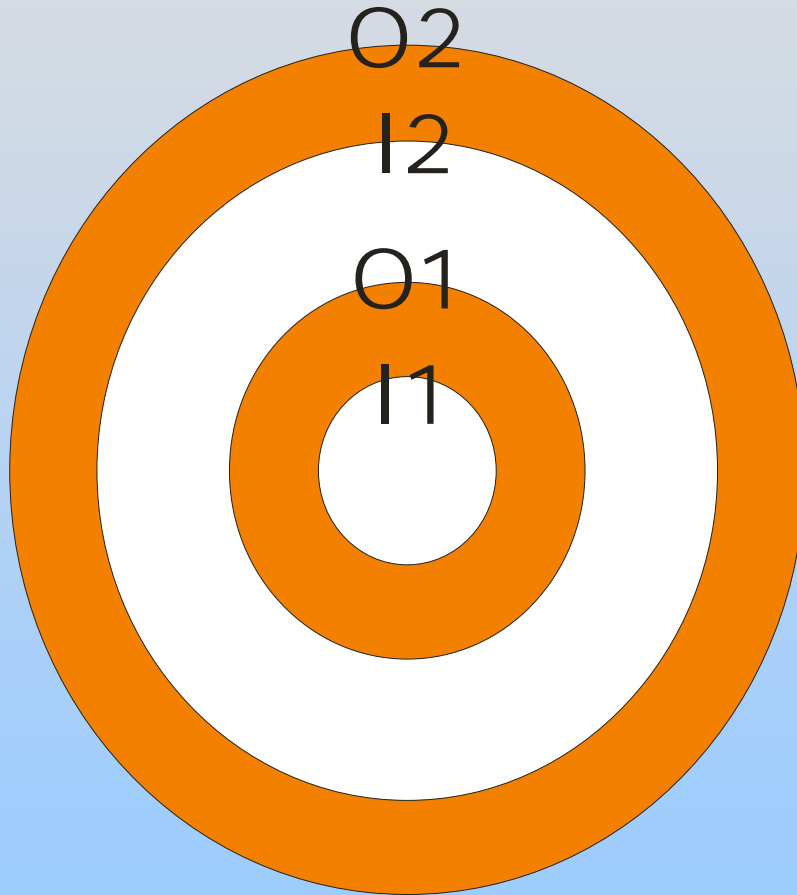
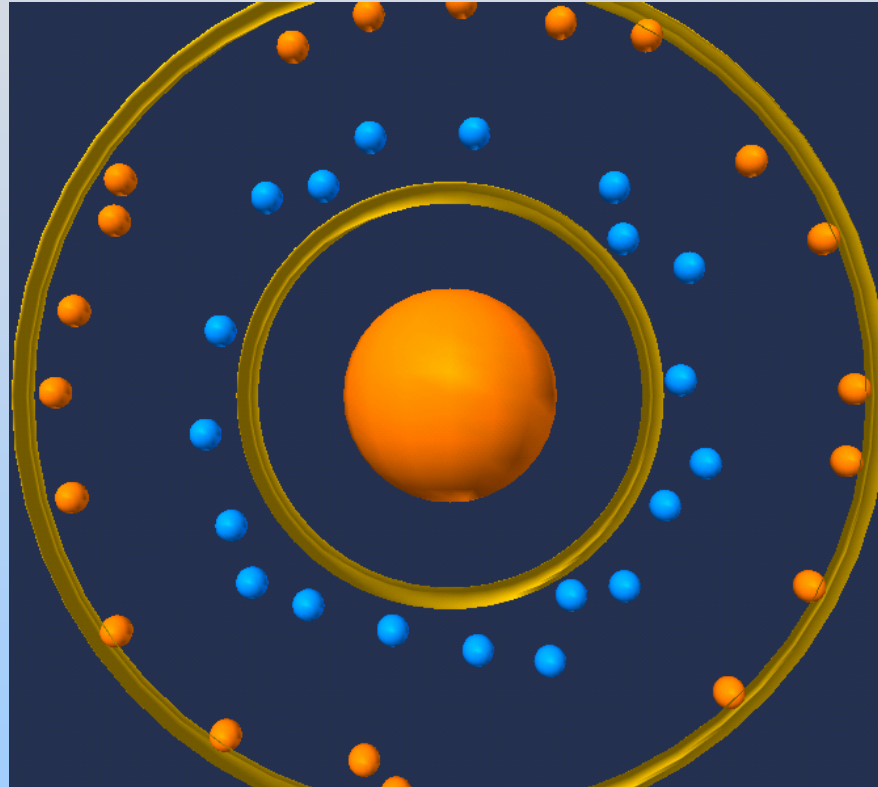Charge placed OUTSIDE induces charge separation on OUTSIDE

PRS Setup

O2
I2
O1
I1

What happens if we put Q in the center?

PRS Questions:
Point Charge
Inside Conductor

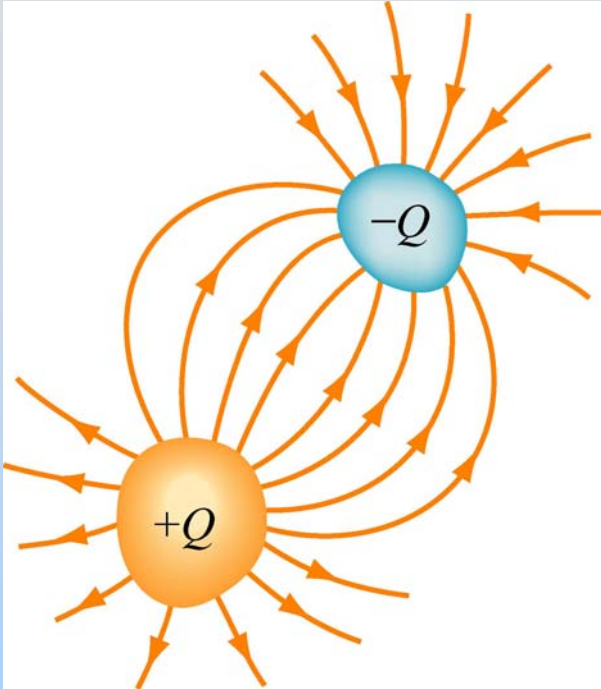# Demonstration: Conductive Shielding

Visualization: Inductive Charging

Experiment 3: Faraday Ice Pail

Last Time: Capacitors

Capacitors: Store Electric Energy
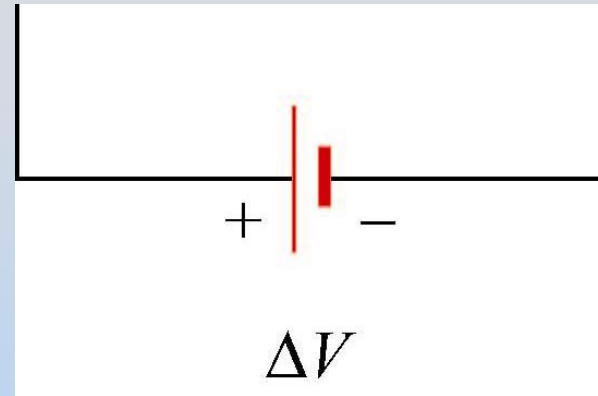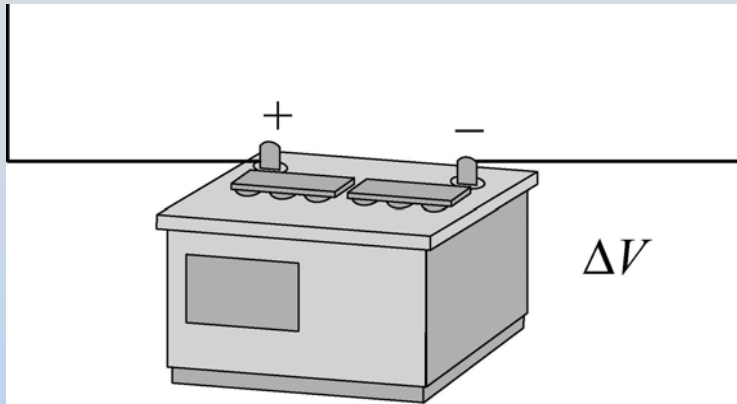

$$C = \frac{Q}{|\Delta V|}$$

To calculate:

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

Parallel Plate Capacitor:

$$C = \frac{\varepsilon_0 A}{d}$$
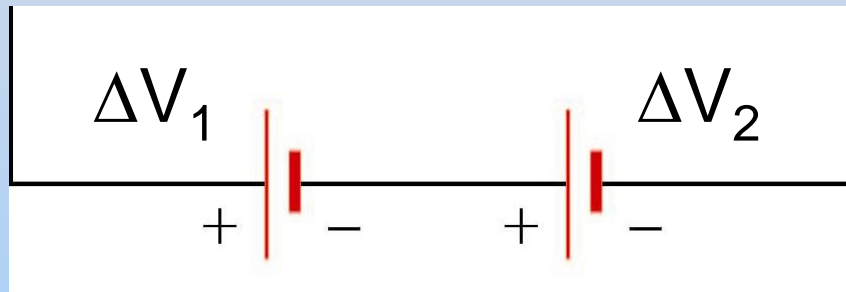
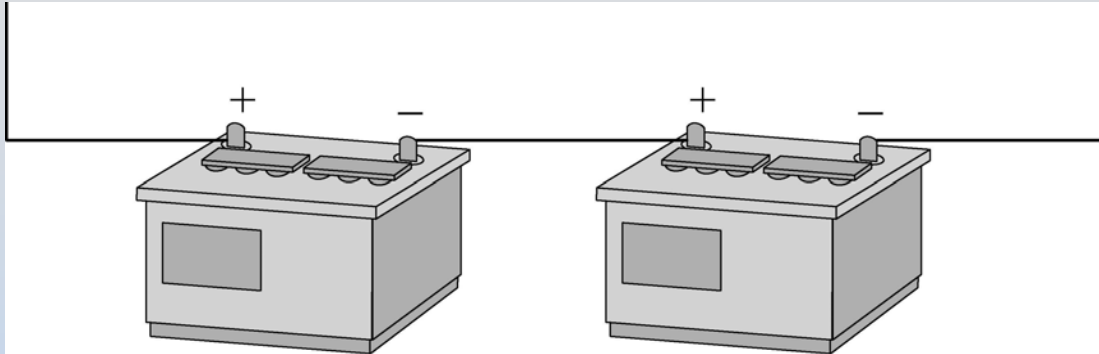# Batteries & Elementary Circuits

Ideal Battery

Fixes potential difference between its terminals

Sources as much charge as necessary to do so

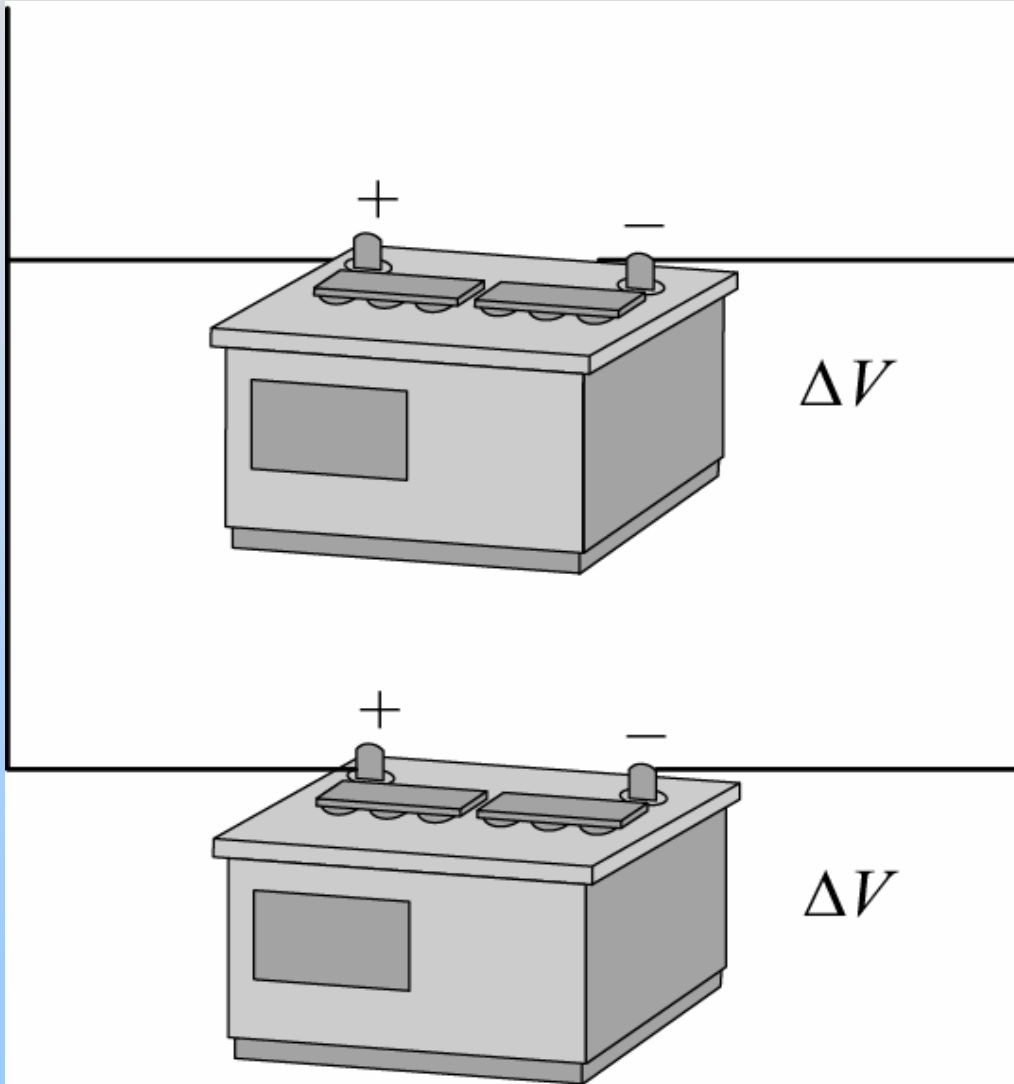**Think**: Makes a mountain

Batteries in Series

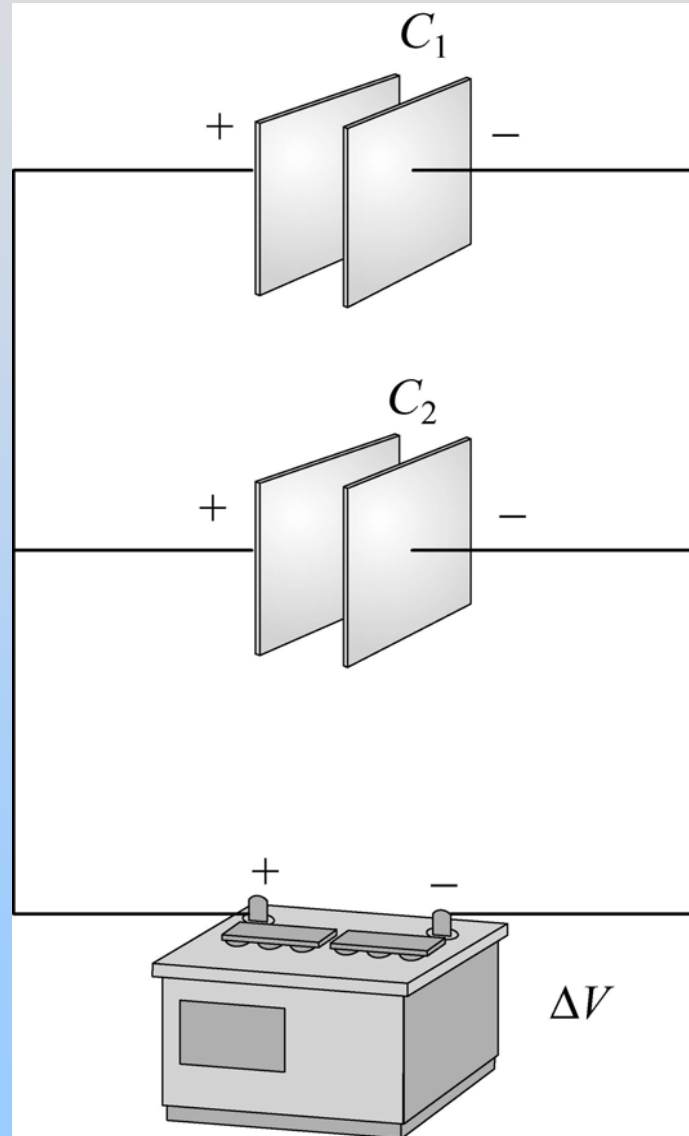Net voltage change is $\Delta V = \Delta V_1 + \Delta V_2$

Think: Two Mountains Stacked

Batteries in Parallel

Net voltage still ΔV

Don't do this!

Capacitors in Parallel

Capacitors in Parallel
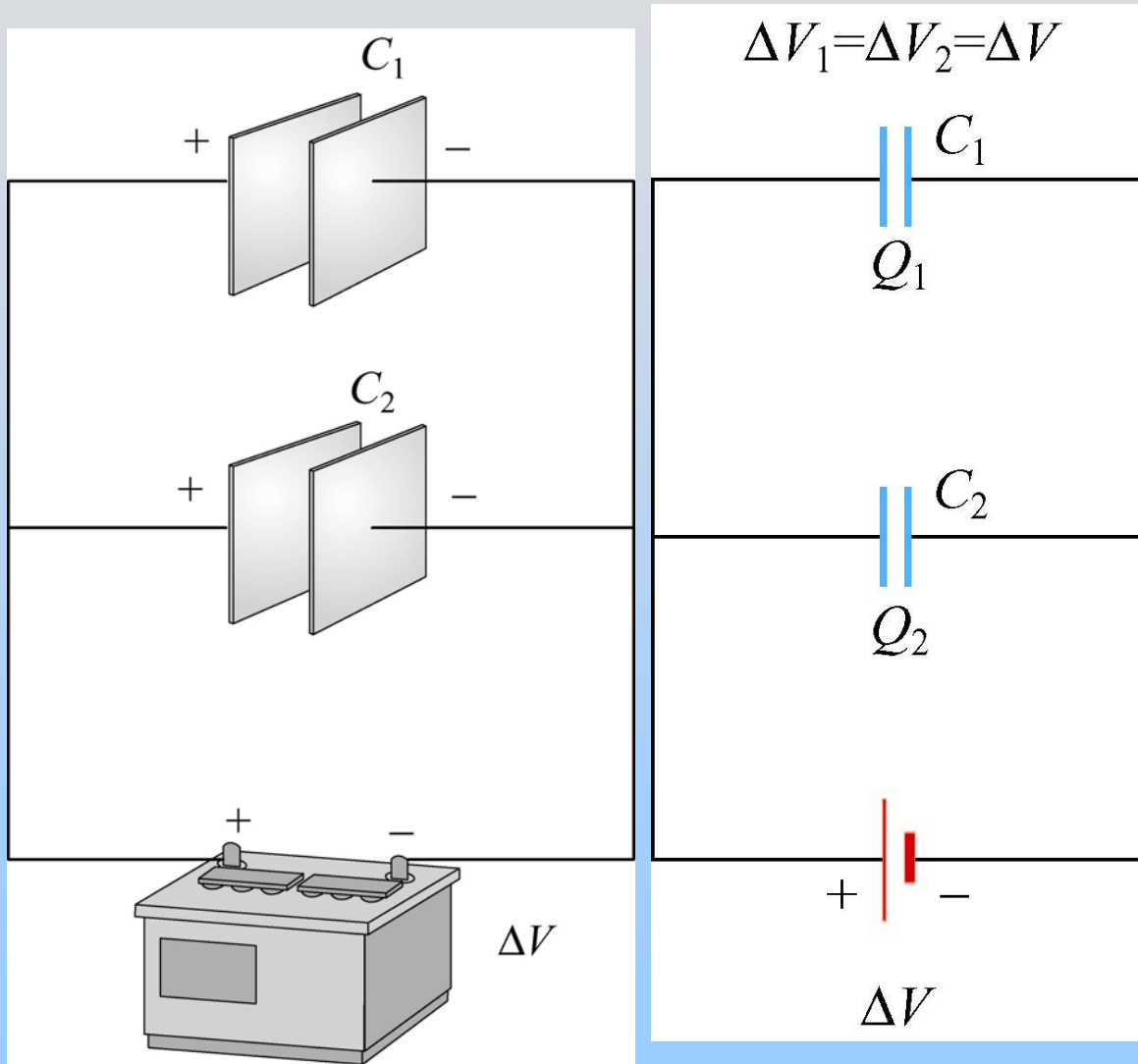
$\Delta V_1 = \Delta V_2 = \Delta V$
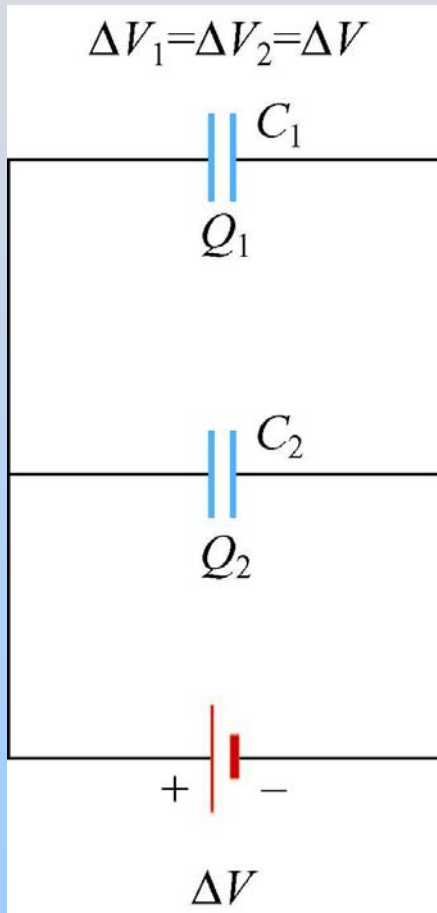
Same potential!
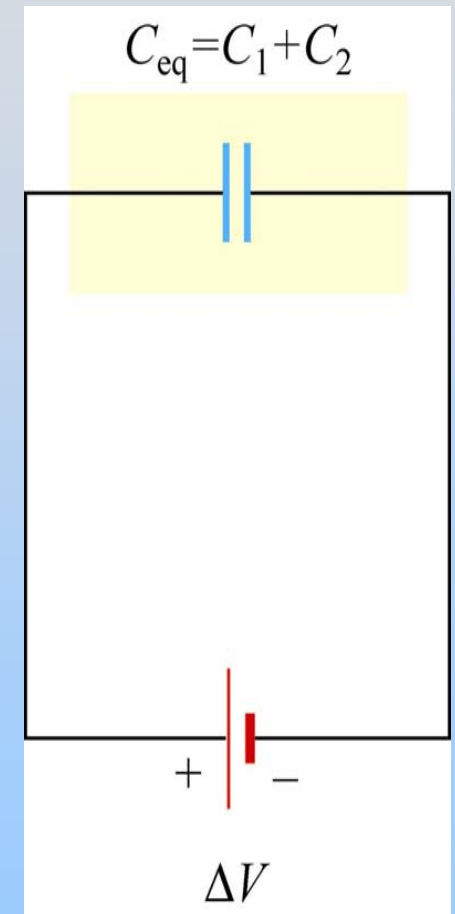
$$C_1 = \frac{Q_1}{\Delta V}, \; C_2 = \frac{Q_2}{\Delta V}$$
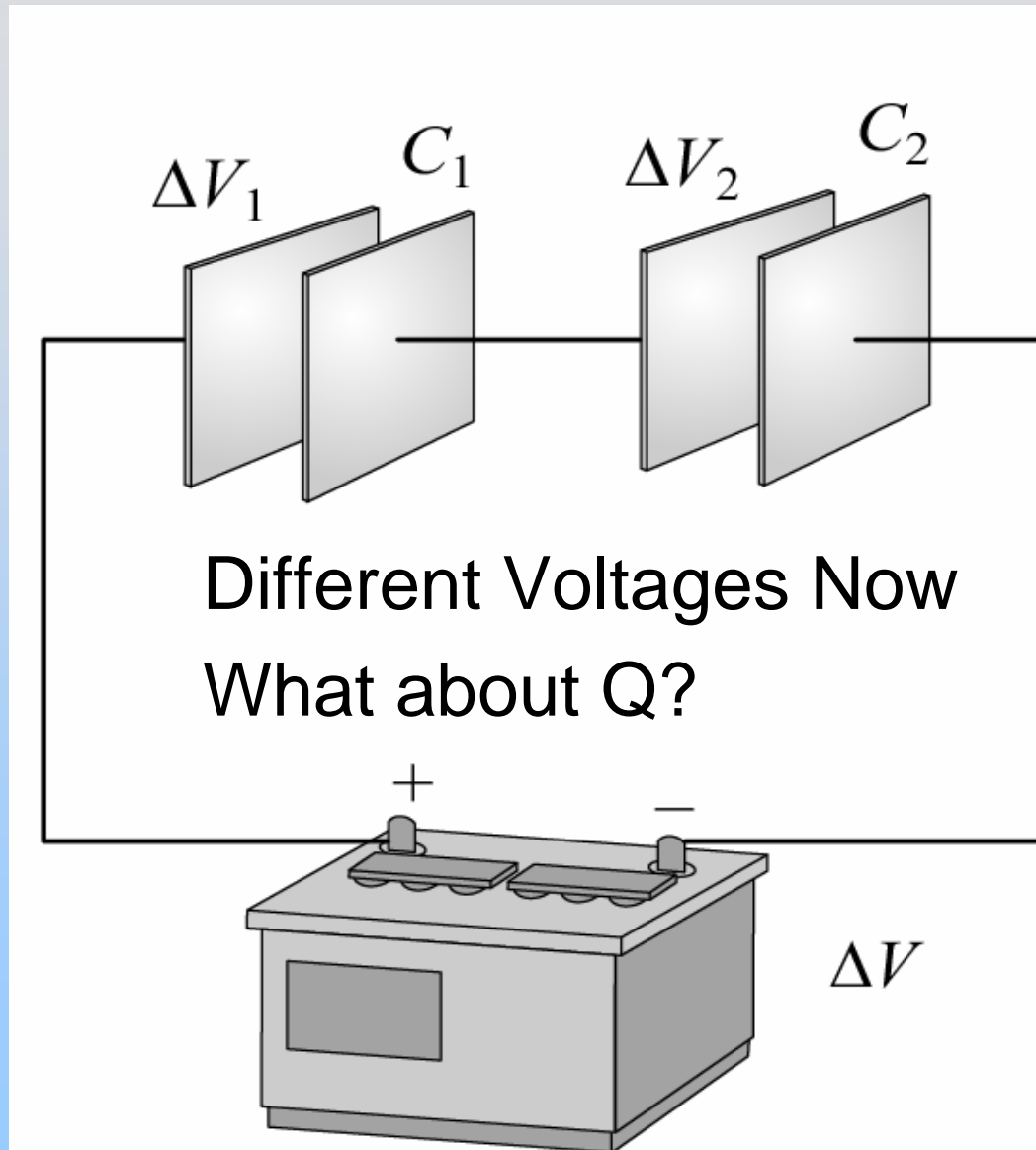
Equivalent Capacitance

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

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

Capacitors in Series

ΔV_1 C_1 ΔV_2 C_2

Different Voltages Now

What about Q?

$+$ $-$

ΔV

Capacitors in Series
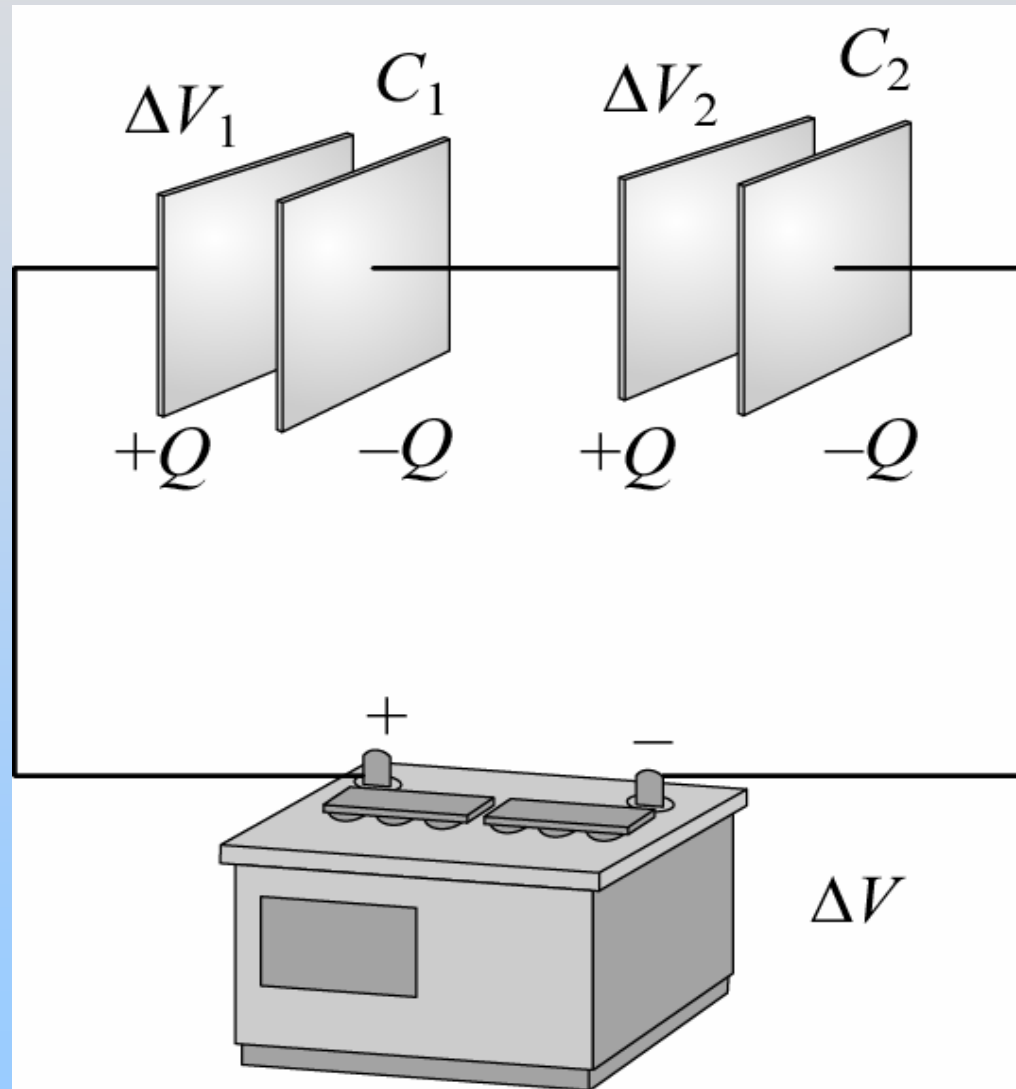
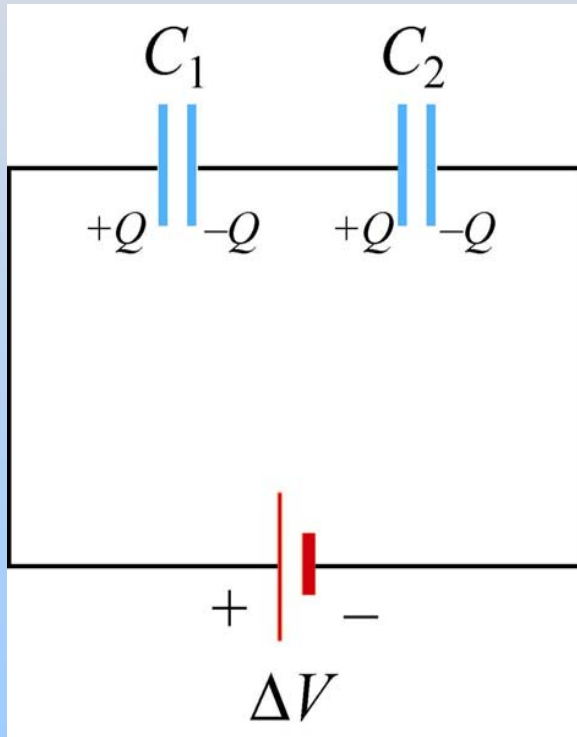# Equivalent Capacitance

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

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

(voltage adds in series)

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

$$\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}}$$
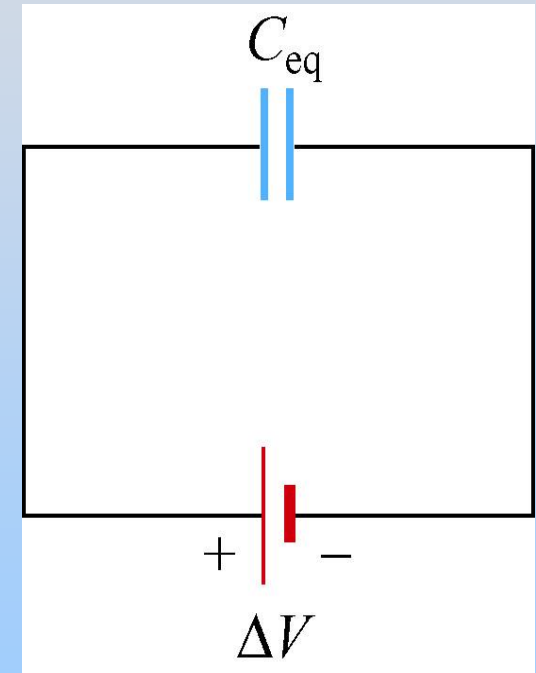
PRS Question: Capacitors in Series and Parallel

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
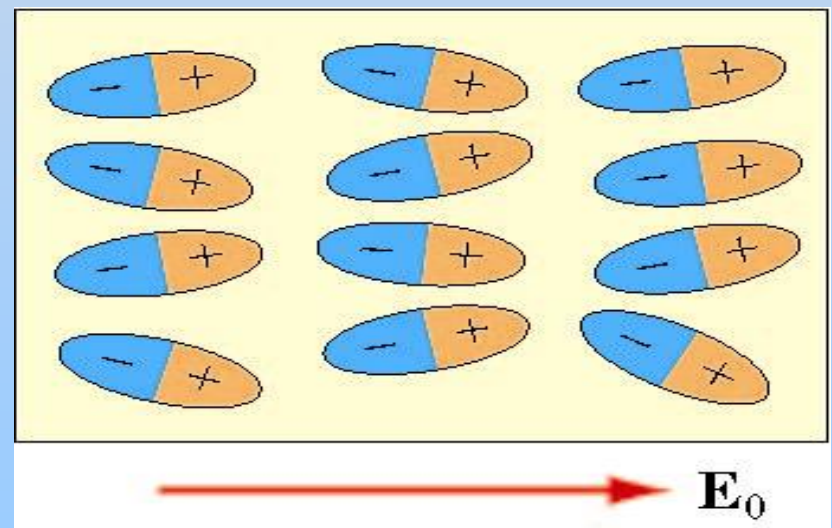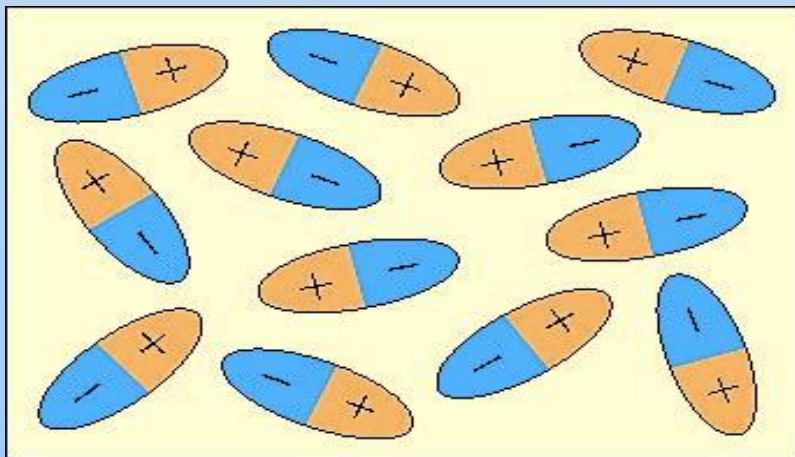
Polar Dielectrics :

Dielectrics with permanent electric dipole moments
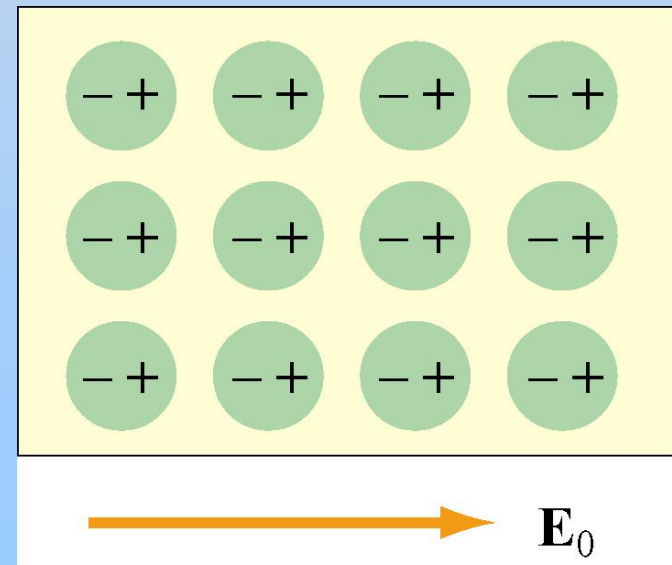**Example: Water**

Molecular View of Dielectrics

Non-Polar Dielectrics

Dielectrics with induced electric dipole moments

Example: CH_4

$E_0=0$

E_0
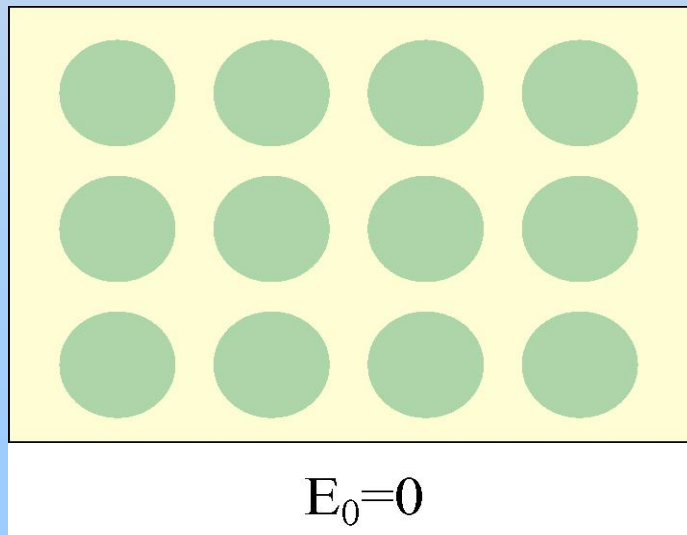
Dielectric in Capacitor
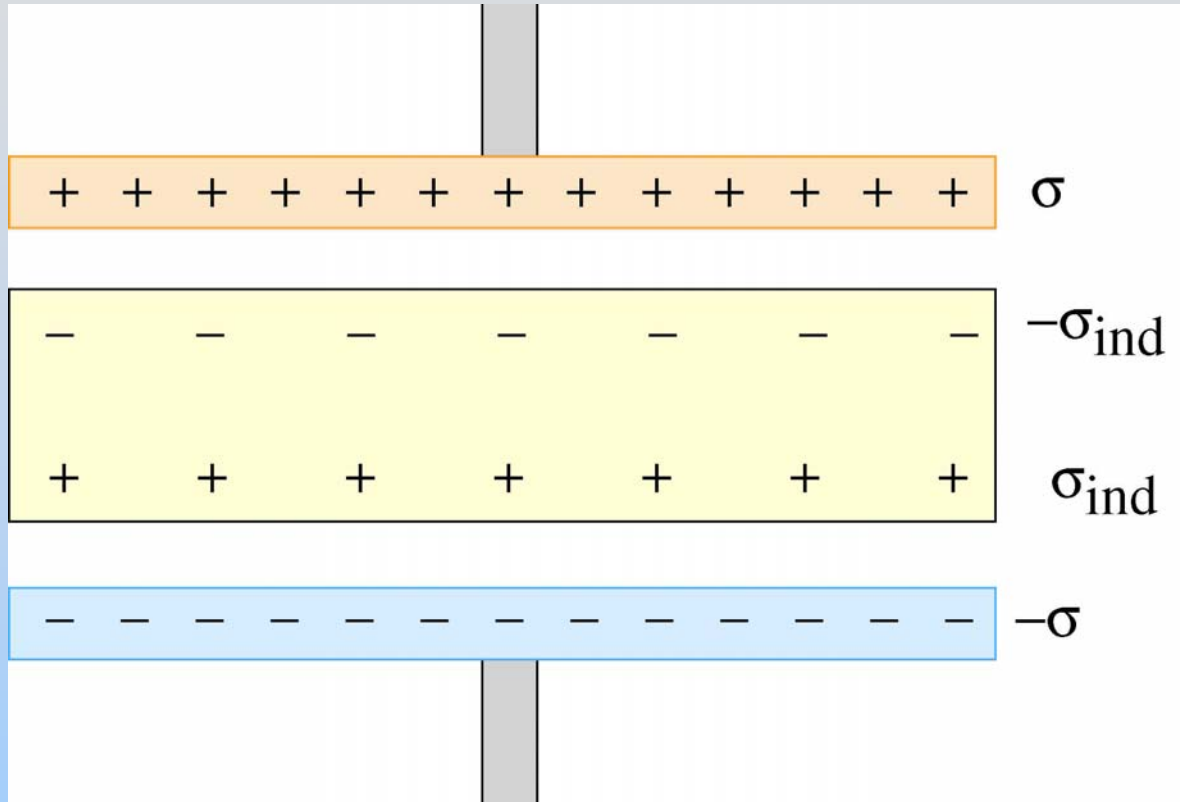
Potential difference decreases because dielectric polarization decreases Electric Field!

Gauss's Law for Dielectrics

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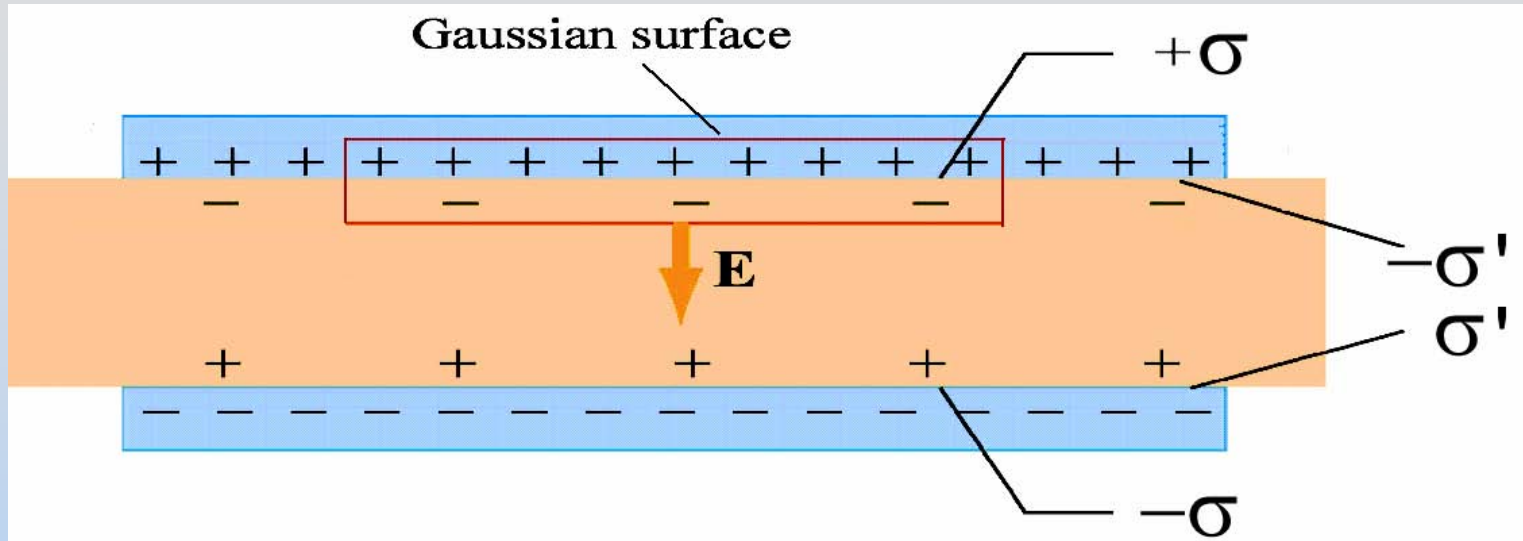
Upon inserting dielectric, a charge density σ' is induced at its surface

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

What is σ'?

Dielectric Constant κ

Dielectric _weakens_ original field by a factor κ

$$E = \frac{\sigma - \sigma'}{\varepsilon_0} \equiv \frac{E_0}{\kappa} = \frac{\sigma}{\kappa \varepsilon_0} \quad \Rightarrow \quad \boxed{\sigma' = \sigma \left(1 - \frac{1}{\kappa}\right)}$$
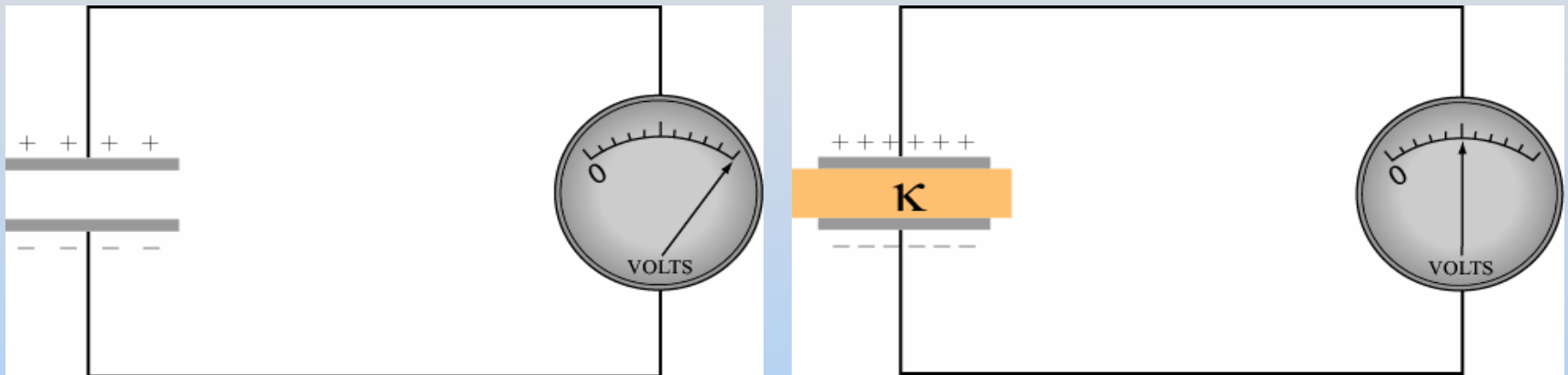
Gauss's Law with dielectrics:

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

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

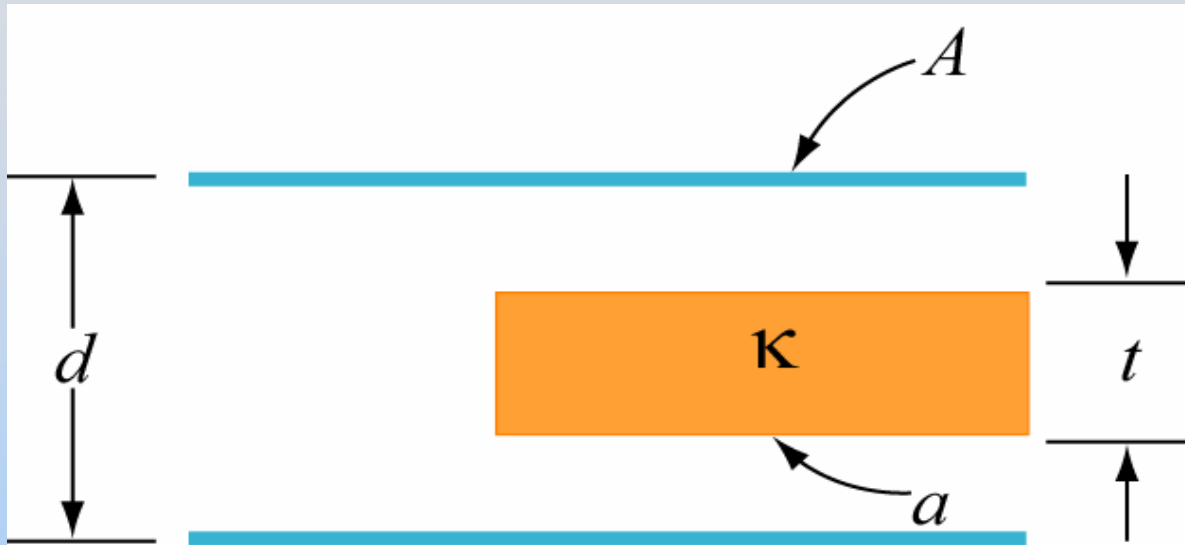**V$_0$ = constant when battery remains connected**
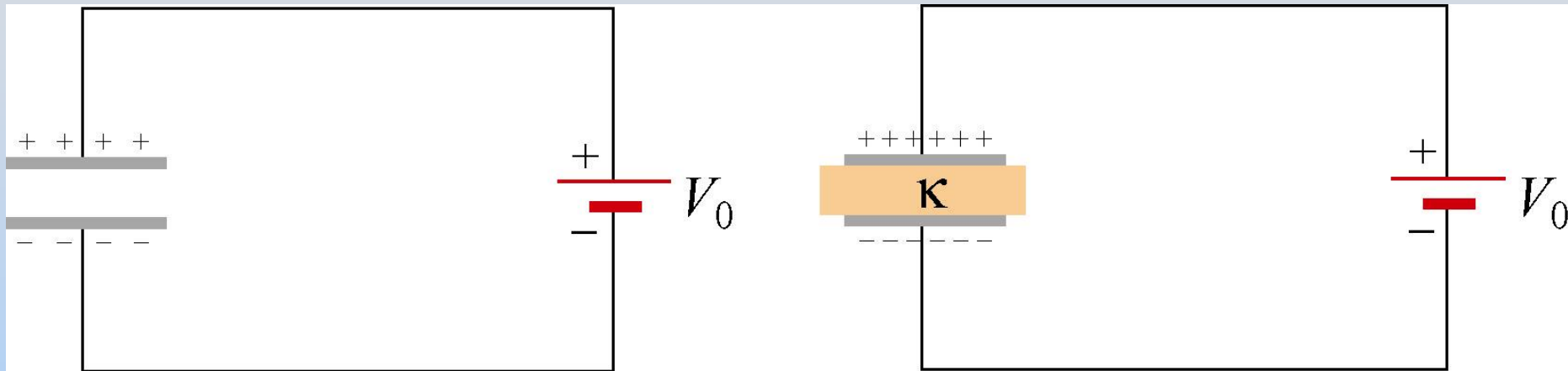
$$C = \frac{Q}{V} = \kappa C_0 = \kappa \frac{Q_0}{V_0}$$

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?