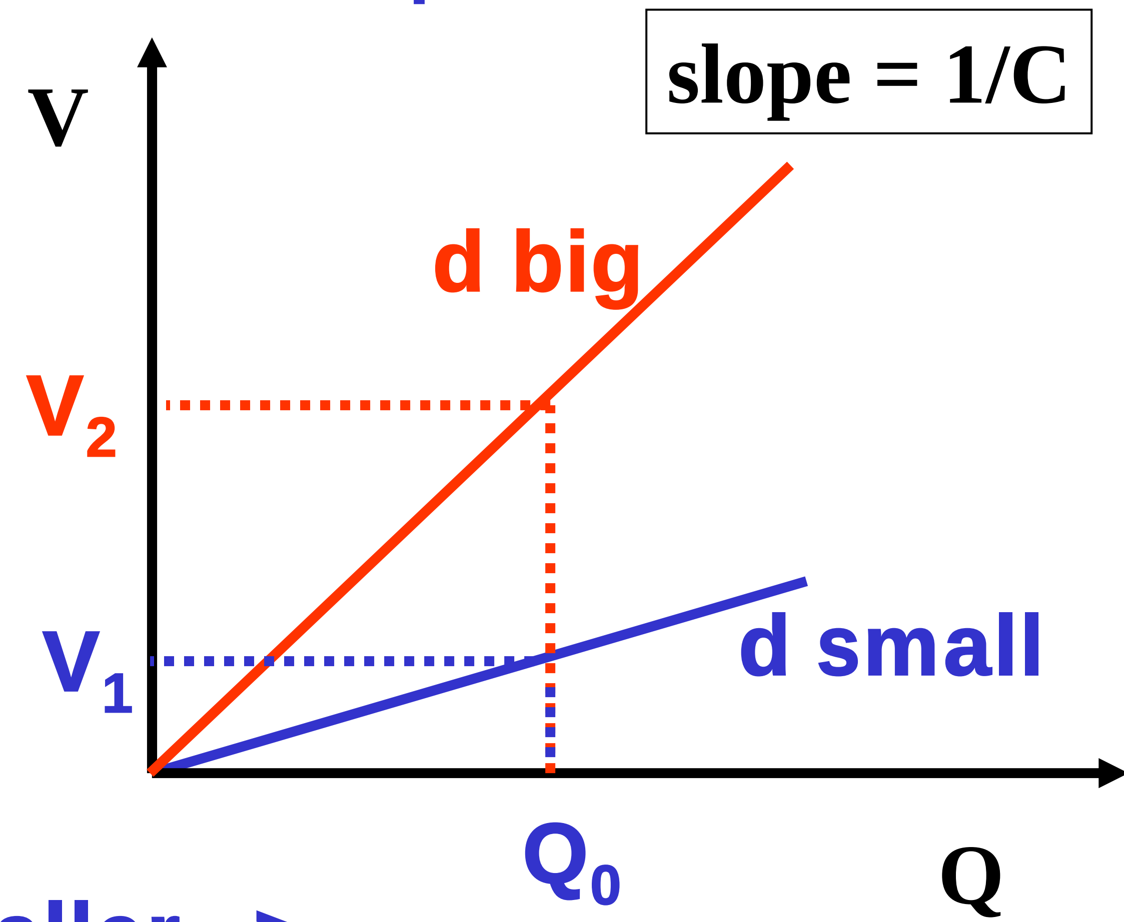
Electricity and Magnetism

- Capacitors
  - Dielectric
- Experiment EF

Parallel Plate Capacitor

$C = \varepsilon_0 A / d$

- Change d
  - change C
- Q constant



d bigger -> C smaller -> V bigger for fixed Q

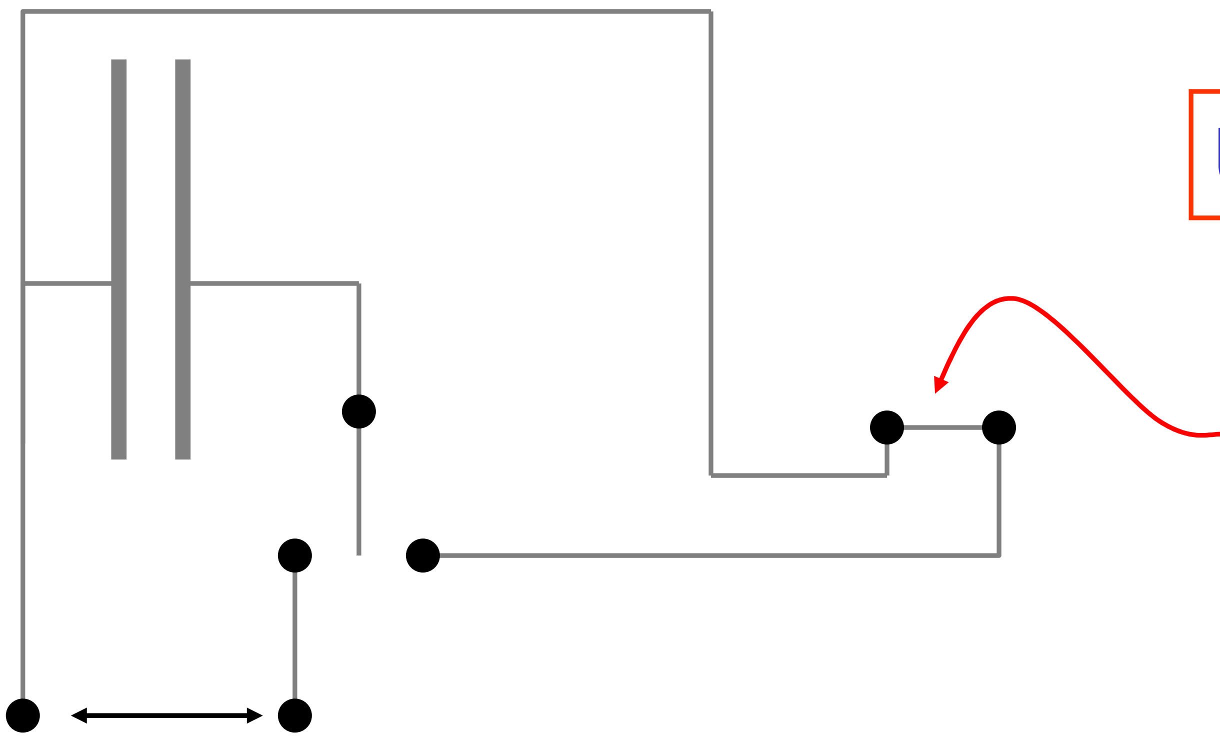
Energy stored in Capacitor

- Can store more energy, if
  - **C** bigger
  - **V** bigger

$$W_{tot} = \frac{1}{2}CV^2$$

In-Class Demo

C = 100μF



U = 800 J

thin wire

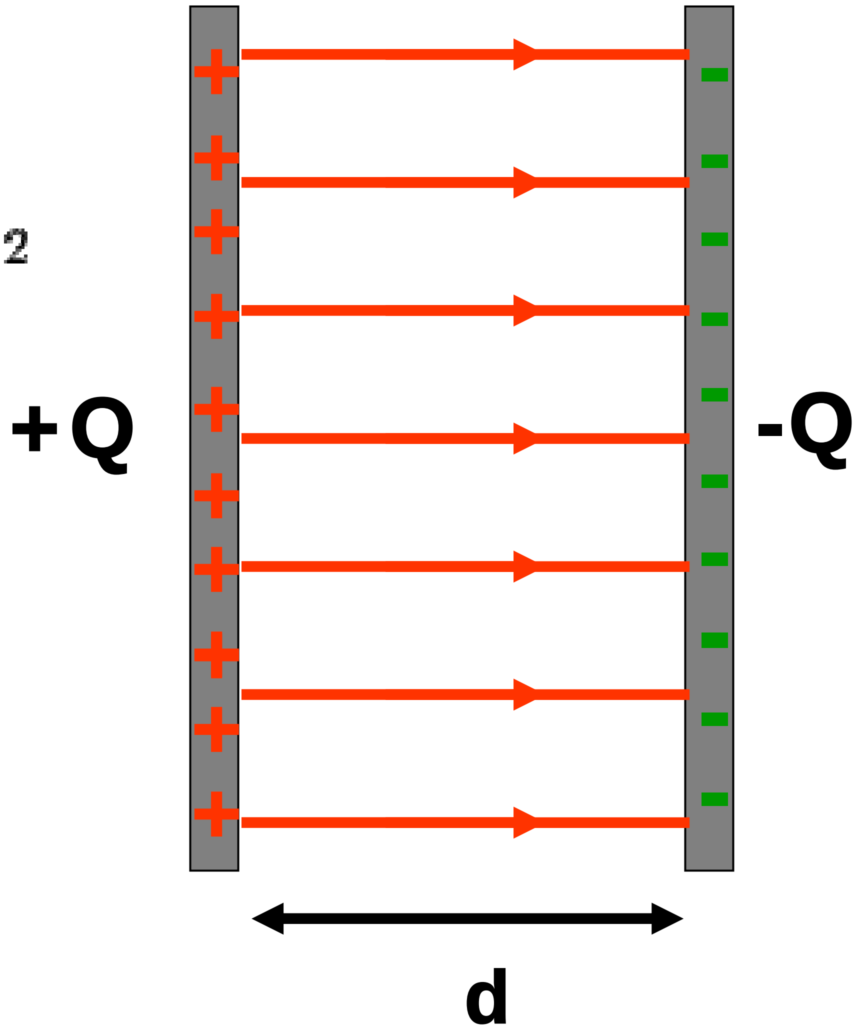
V_{ab} = 4000 V

Where is the energy stored?

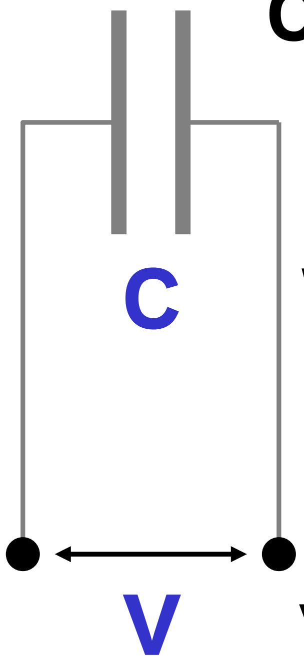
- Energy is stored in Electric Field

$$U_{stored} = \frac{1}{2}CV^2 = \frac{1}{2}(\epsilon_0 \frac{A}{d})(E\ d)^2$$
$$= \boxed{\frac{1}{2}\epsilon_0 E^2\ Volume}$$

- E^2 gives Energy Density:
- **U/Volume = ½ e_0 E^2**



Electric Circuits

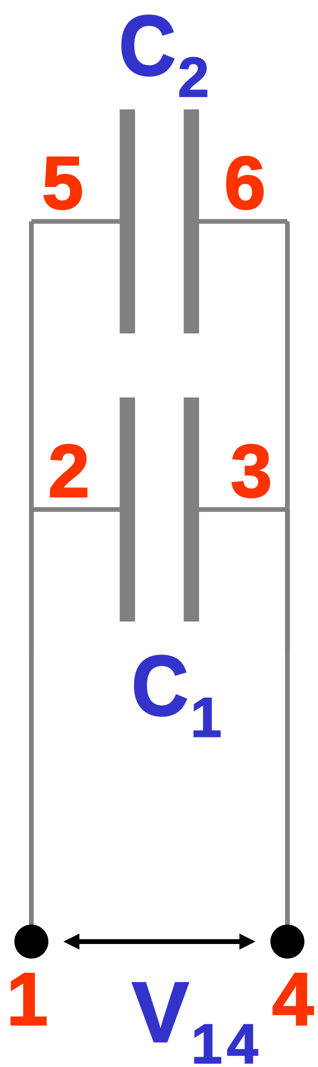


Capacitor

Wire

Voltage source (like LVPS)

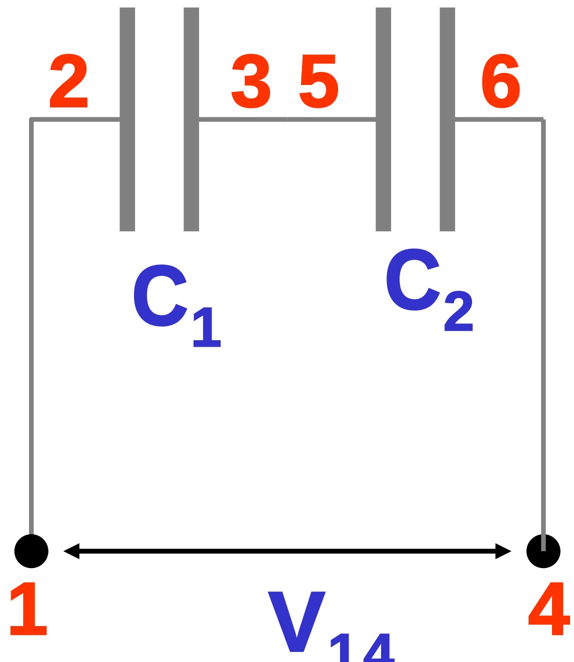
Electric Circuits



- Two capacitors in **parallel**
- $V_{56} = V_{23} = V_{14}$ (after capacitor is charged)
- $Q_1/C_1 = Q_2/C_2 = V_{14}$
- $Q_{tot} = Q_1 + Q_2$
- $C_{tot} = (Q_1 + Q_2)/V_{14} = C_1 + C_2$

- Capacitors in **parallel -> Capacitances add!**

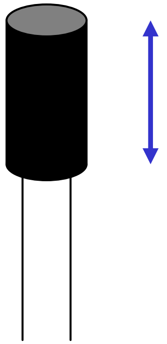
Electric Circuits



- Two capacitors in **series**
- $V_{14} = V_{23} + V_{56}$
- $Q = Q_1 = Q_2$
- $V_{tot} = Q_1/C_1 + Q_2/C_2 = Q/(C_1+C_2)$
- $1/C_{tot} = 1/C_1 + 1/C_2$
- **Inverse Capacitances add!**

Dielectrics

In your toolbox:

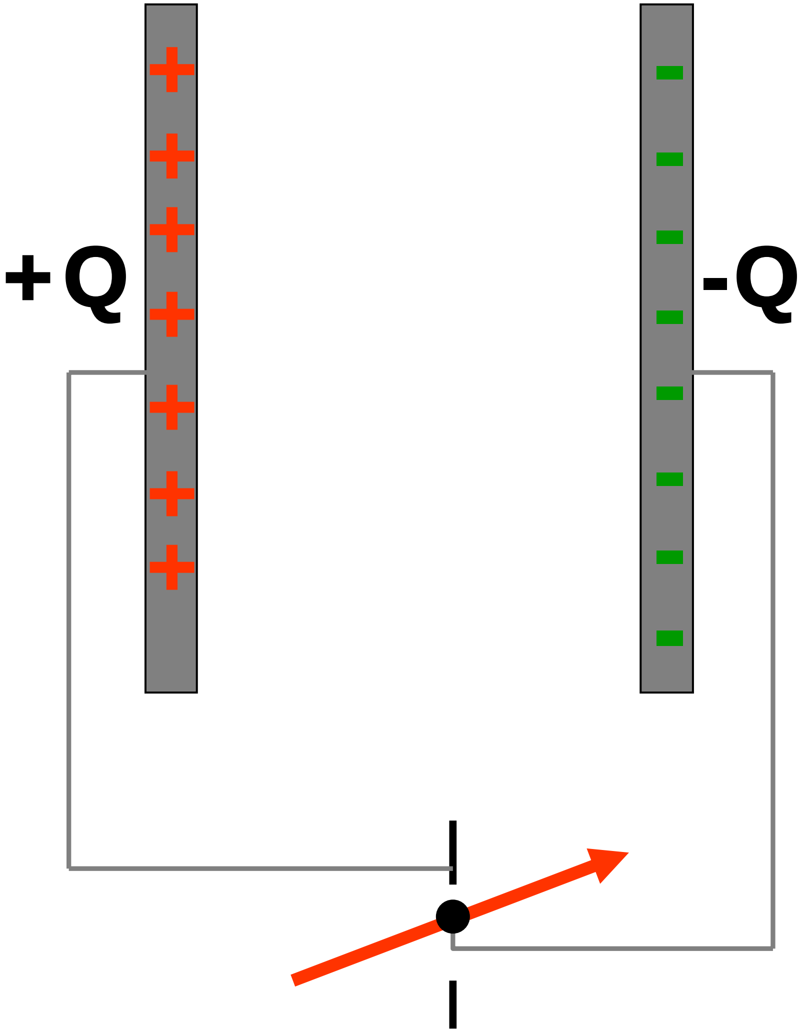


2 cm

C = 1000μF

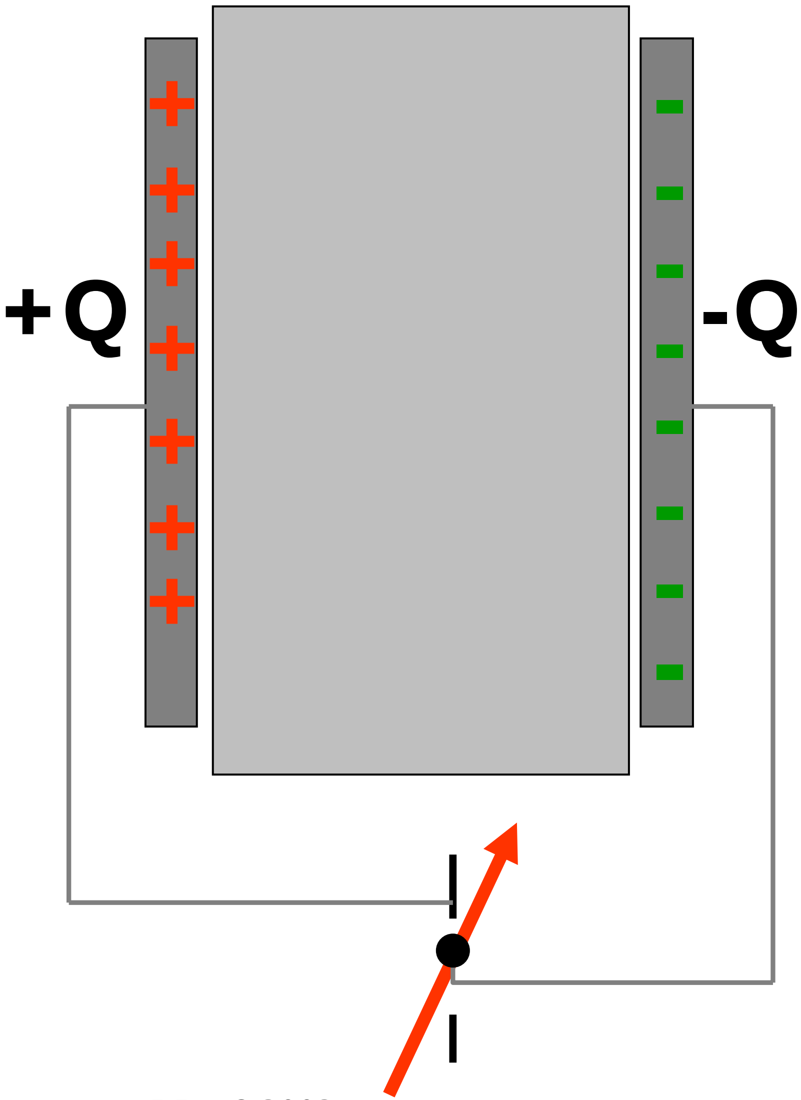
- Parallel Plate Capacitor:
  - **$C = \varepsilon_0 A/d$**
  - Ex. **$A = 1m^2$, $d=0.1mm$ -> $C \sim 0.1\mu F$**
- How do they do that?
- Where to get a factor of 10000?

Dielectric Demo



- Start w/ charged capacitor
- **d** big -> **C** small -> **V** large

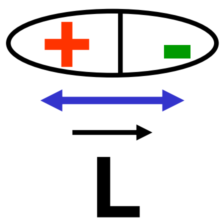
Dielectric Demo



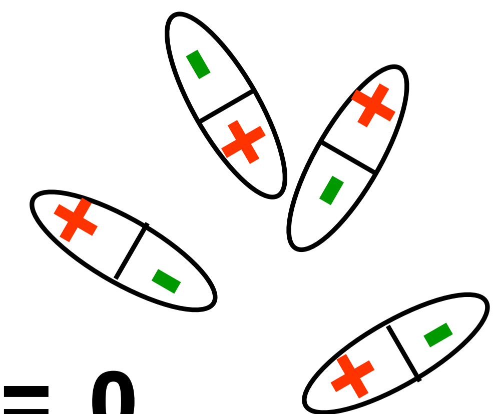
- Start w/ charged capacitor
- **d** big -> **C** small -> **V** large
- Insert Glass plate
- Now **V** much smaller
- **C** bigger
- But **A** and **d** unchanged !
- Glass is a **Dielectric**

Microscopic view

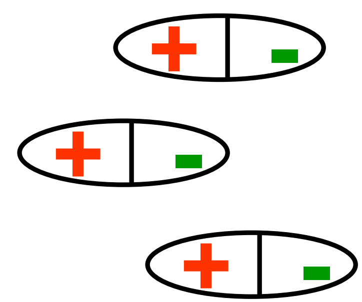
Remember: Dipoles



Dipole Moment $\vec{p} = q\,\vec{L}$

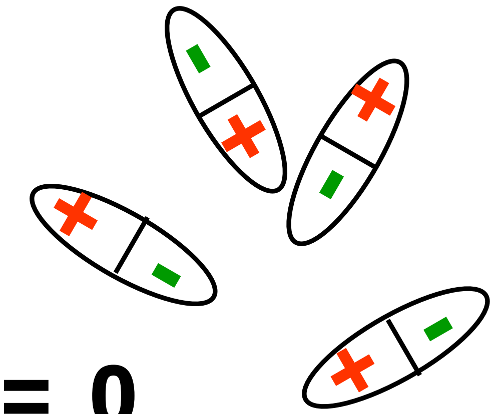


$\vec{E} = 0$

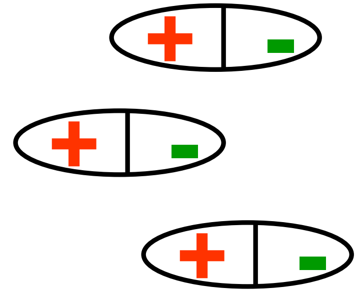


$\vec{E} > 0$

Microscopic view



$\vec{E} = 0$



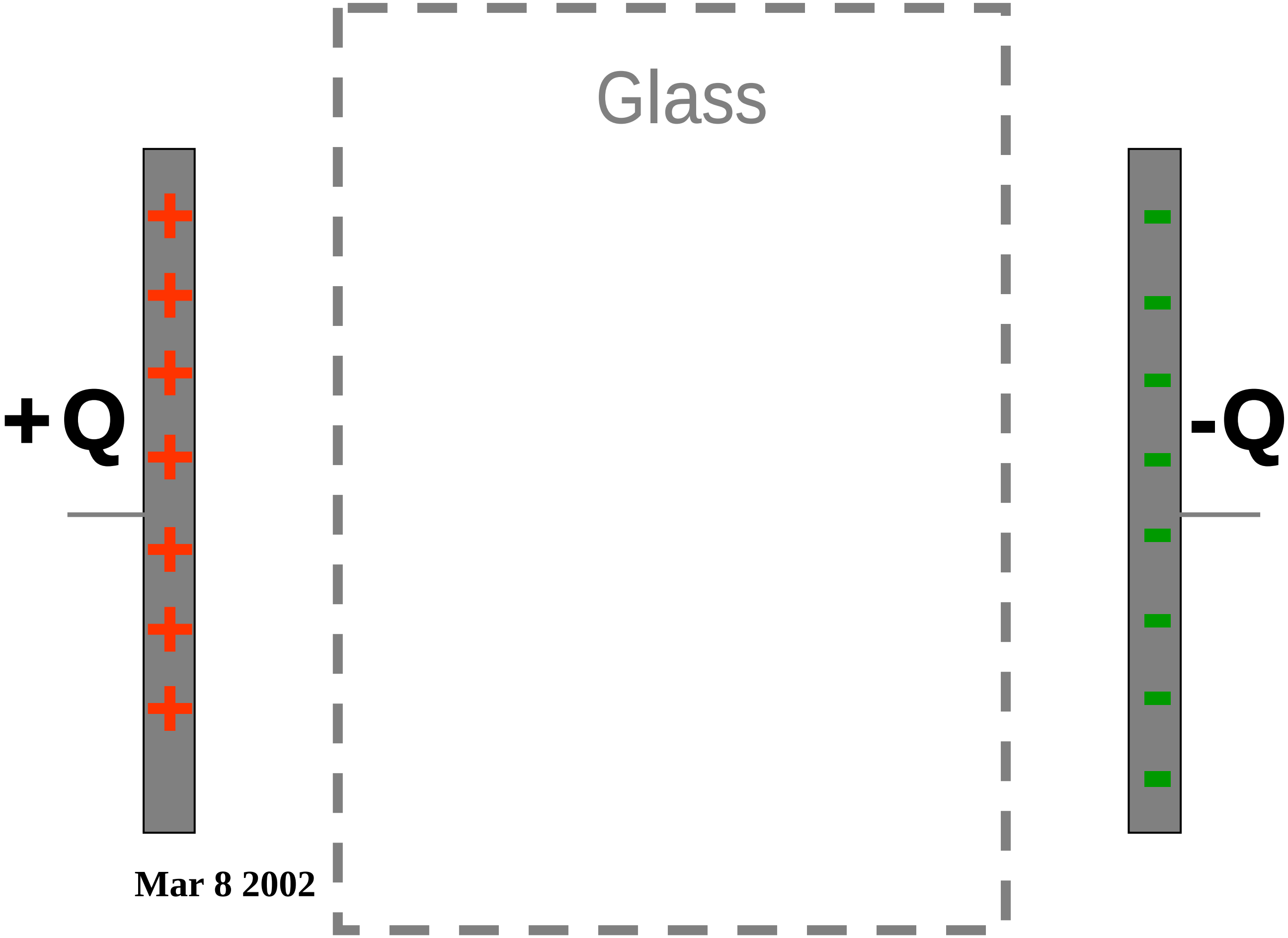
$\vec{E} > 0$

Def: **Polarization** $\vec{P} = n \, \langle \vec{p} \rangle = \text{const.} \, \vec{E}$

Density: #dipoles/volume

Microscopic view

Polarization $\vec{P} = \text{const. } \vec{E} = \varepsilon_0 \chi \vec{E}$



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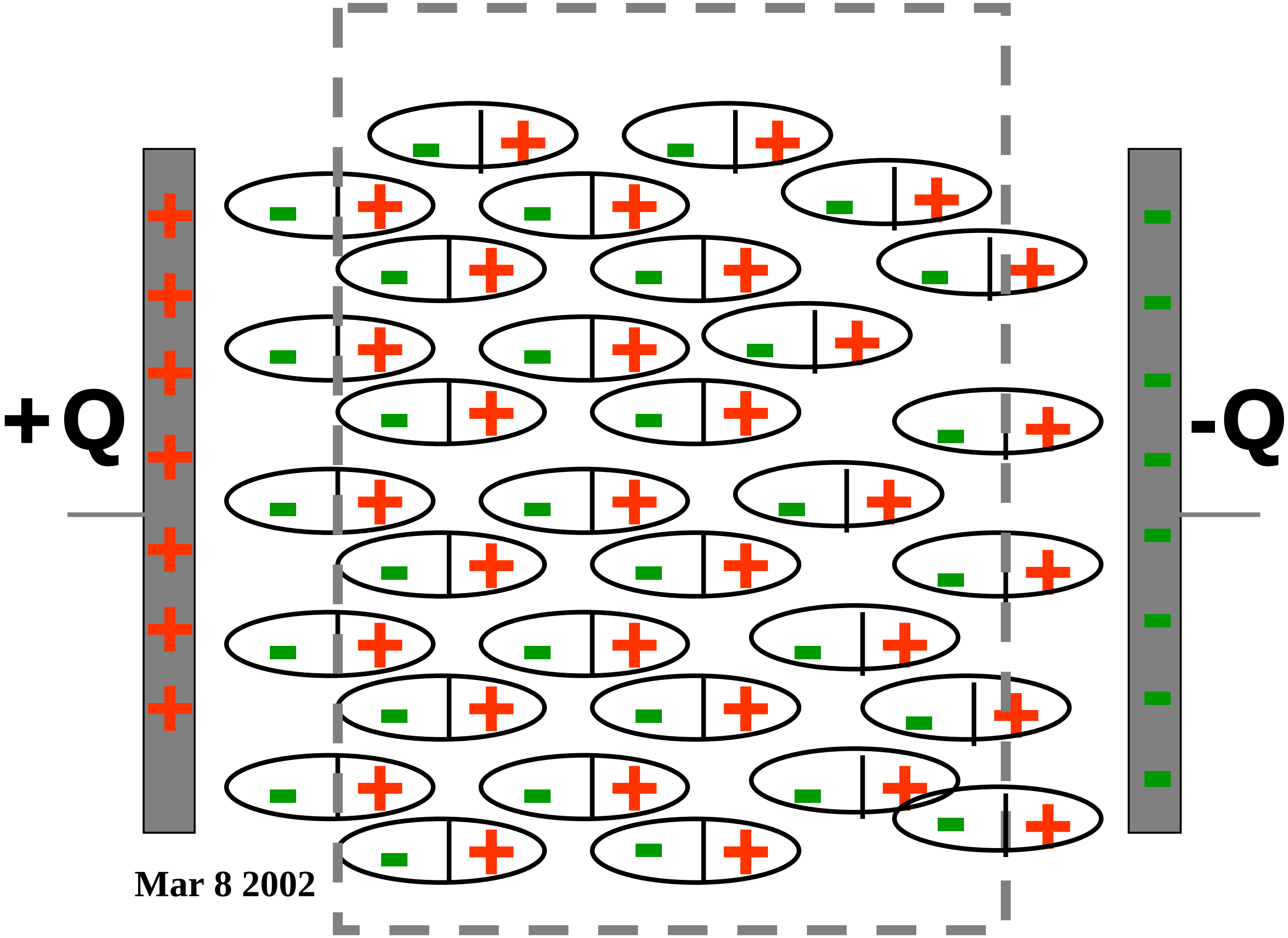
Microscopic view

Polarization $\vec{P} = \text{const. } \vec{E} = \varepsilon_0 \chi \vec{E}$



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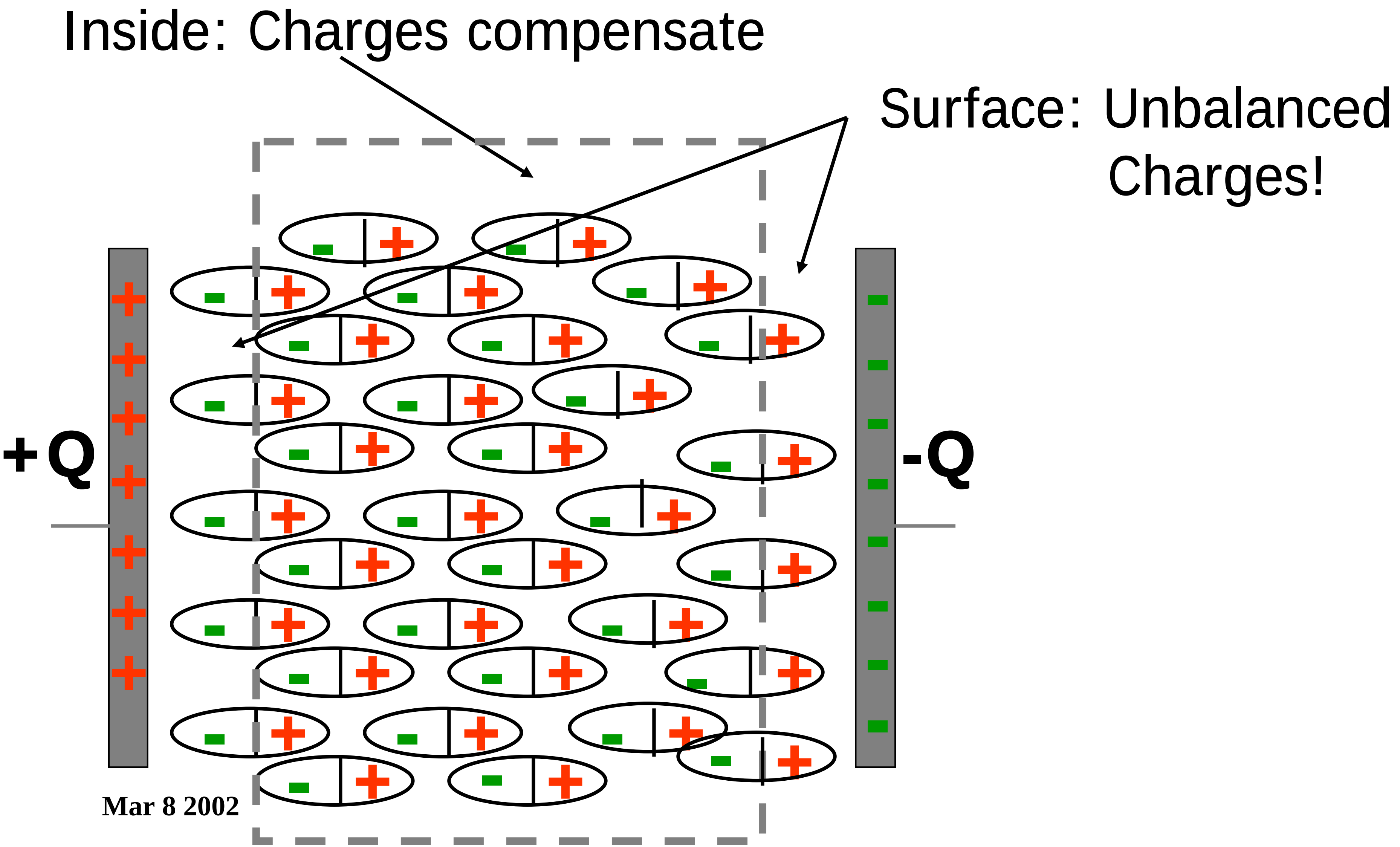
Microscopic view



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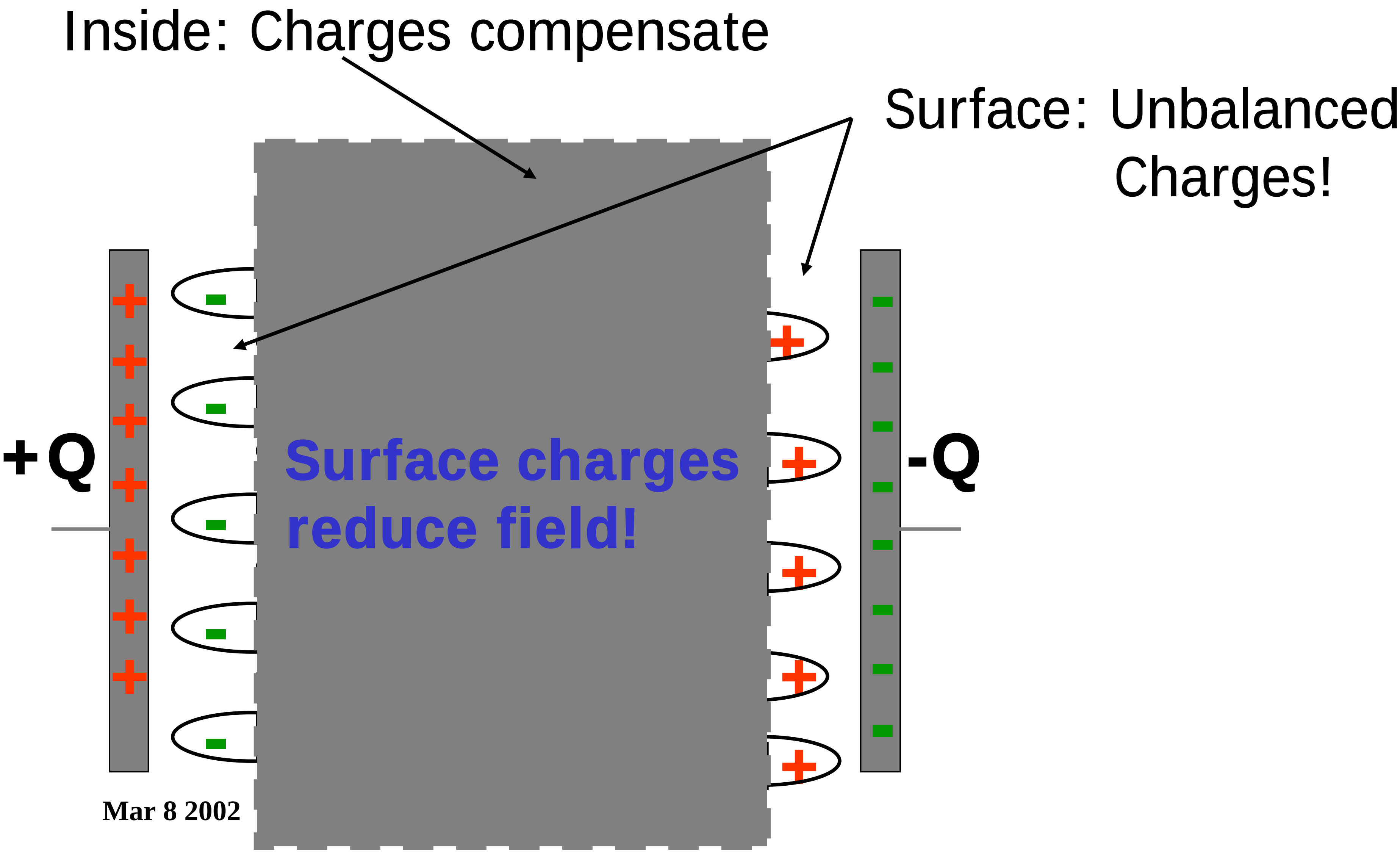
Microscopic view



Dielectric Constant

$$|\sigma_p^+| = |\sigma_p^-| = \frac{|Q_p|}{A}$$ Surface charge density

$$= \frac{n\ q\ L\ A}{A}$$

$$= np$$

$$= P$$ Polarization

Dielectric Constant

$$E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} - \frac{|\sigma_p^+|}{2\epsilon_0} - \frac{|\sigma_p^-|}{2\epsilon_0|}$$

Add contributions to E

$$= \frac{\sigma}{\epsilon_0} - \frac{P}{\epsilon_0}$$

E from plates and E from Dielectric surface charge

$$= E_0 + \chi E$$

K: Dielectric Constant

$$\rightarrow E = \frac{E}{1+\chi} \equiv \frac{E_0}{K}$$

Field w/o Dielectric

Dielectric Constant

- Dielectric reduces field E_0 ($K > 1$)
  - $E = 1/K\ E_0$
- Dielectric increases Capacitance
  - $C = Q/V = Q/(E\,d) = K\,Q/(E_0 d)$
- This is how to make small capacitors with large **C** !

Dielectric Constant

- Examples

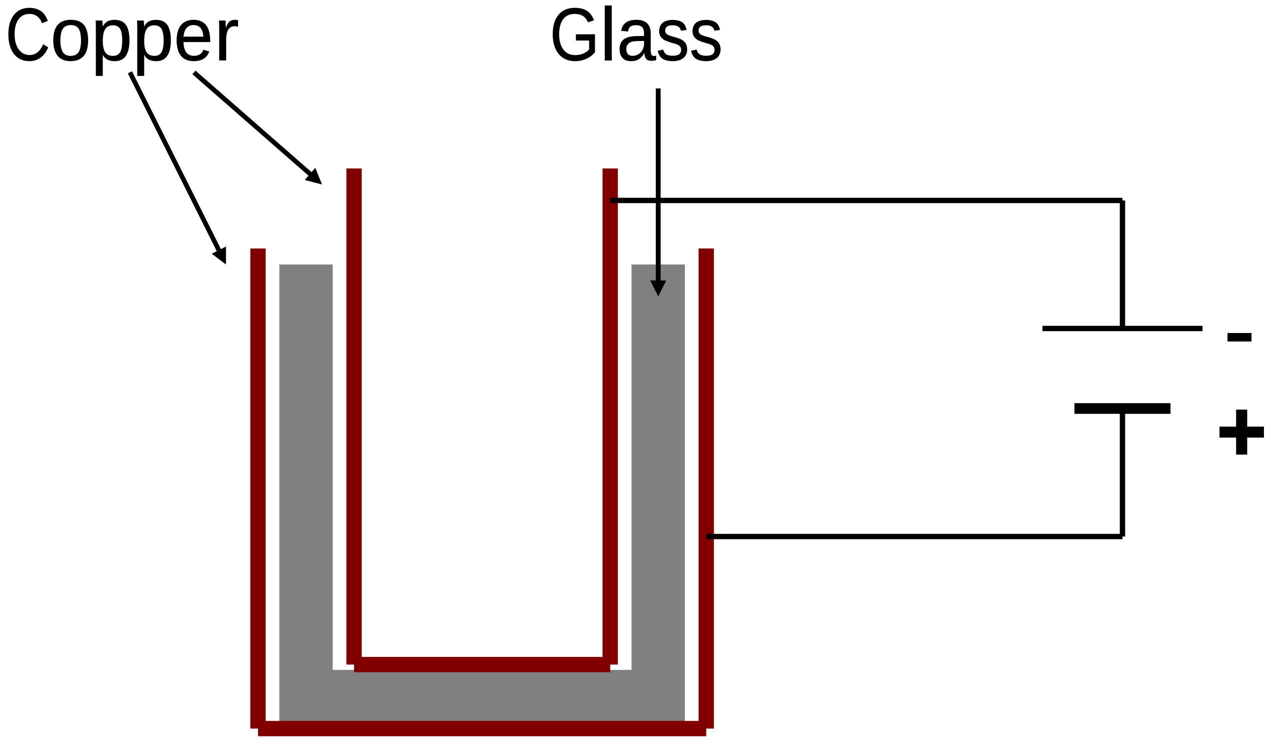
Material	K
Vacuum	1
Air	1.0006
Plexiglass	3.4
Water	80.4
Ethanol	23
Ceramics	~5000
Glass	5-10

Similar to vacuum

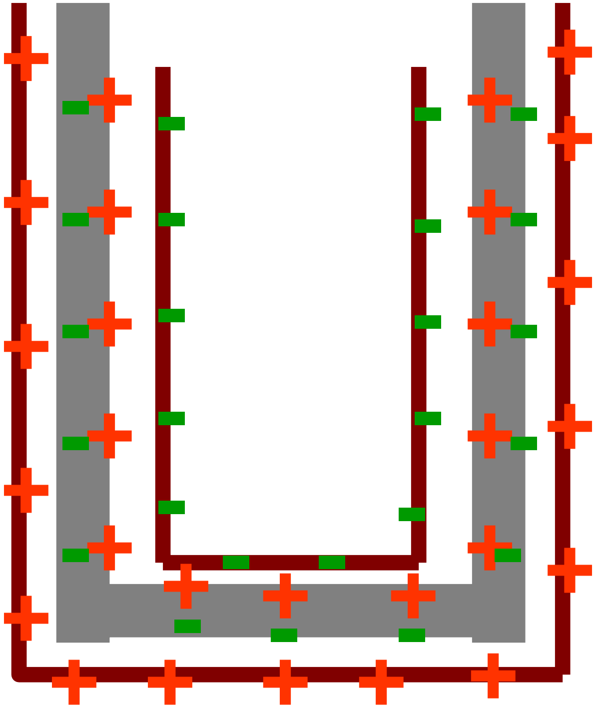
Large!

C in HVPS

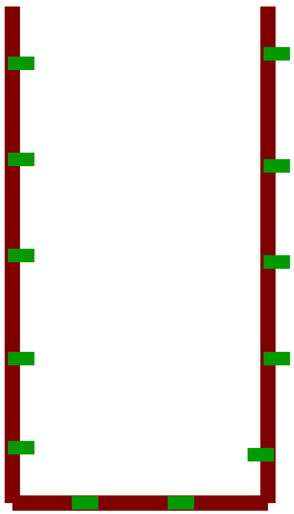
'Puzzle' Demo

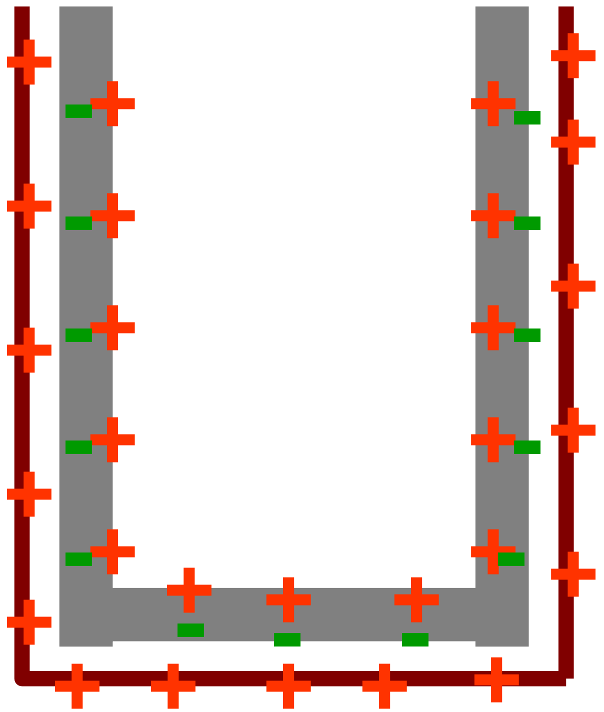


‘Puzzle’ Demo



‘Puzzle’ Demo





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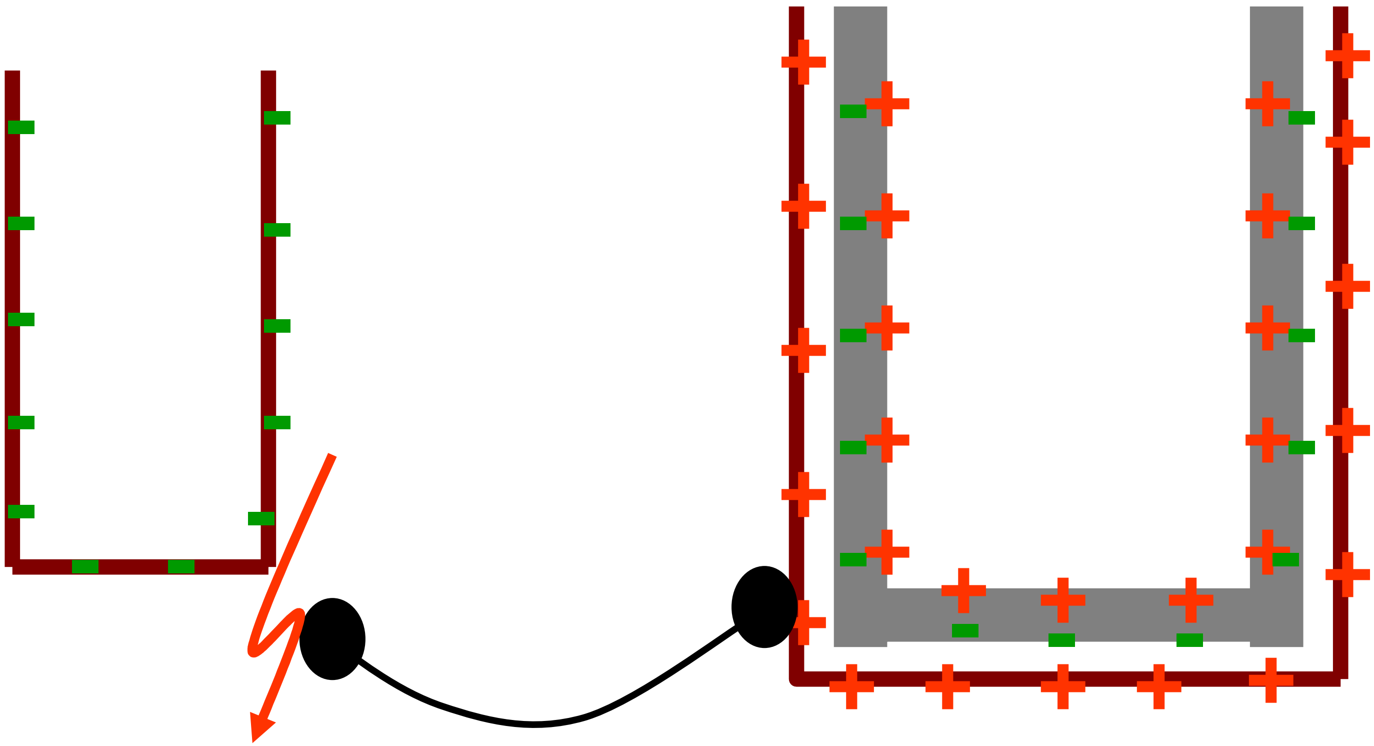

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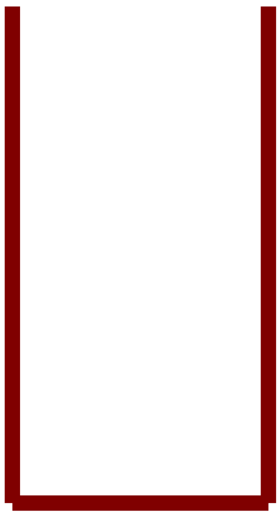
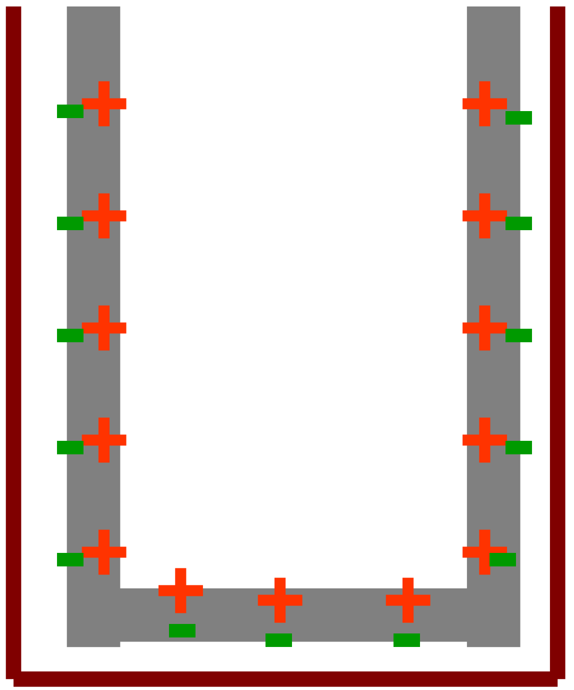
‘Puzzle’ Demo





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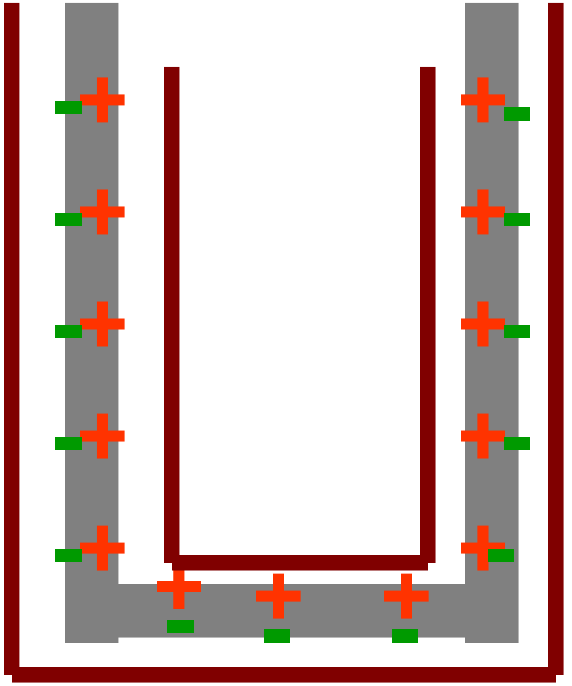
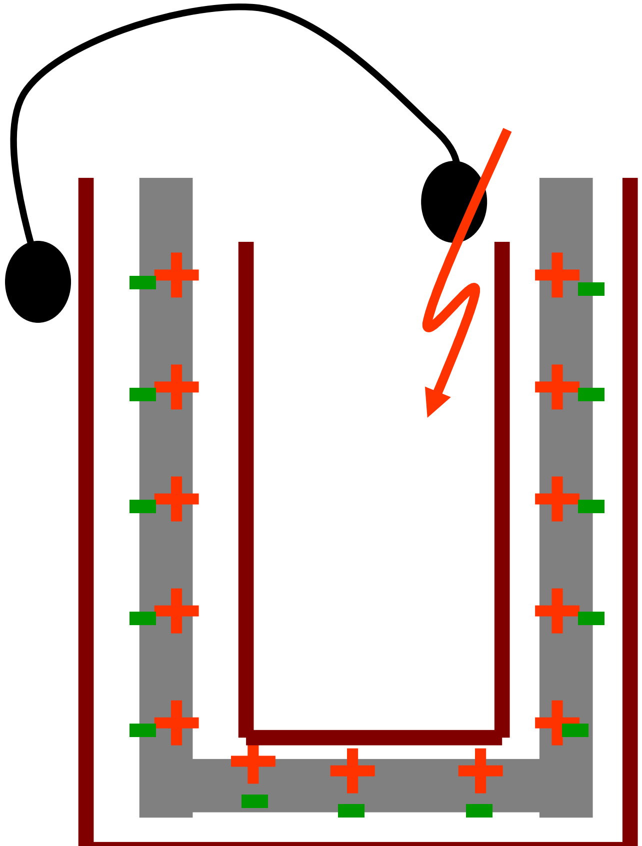
‘Puzzle’ Demo

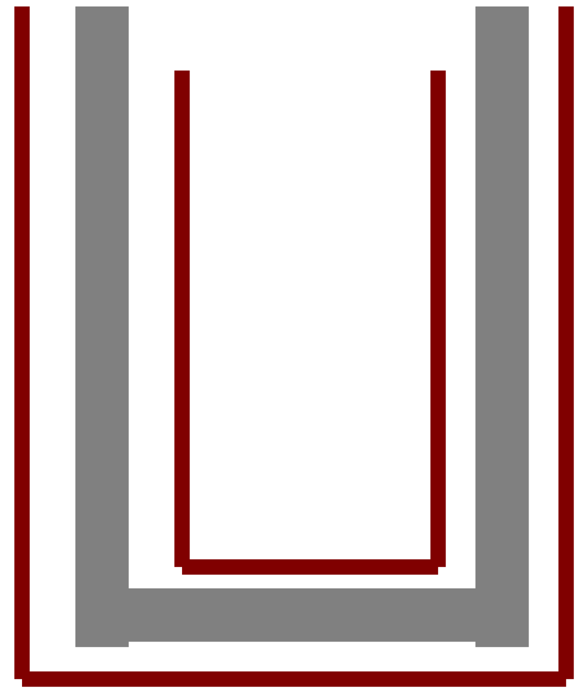
Surfaces charges remain on Glass !



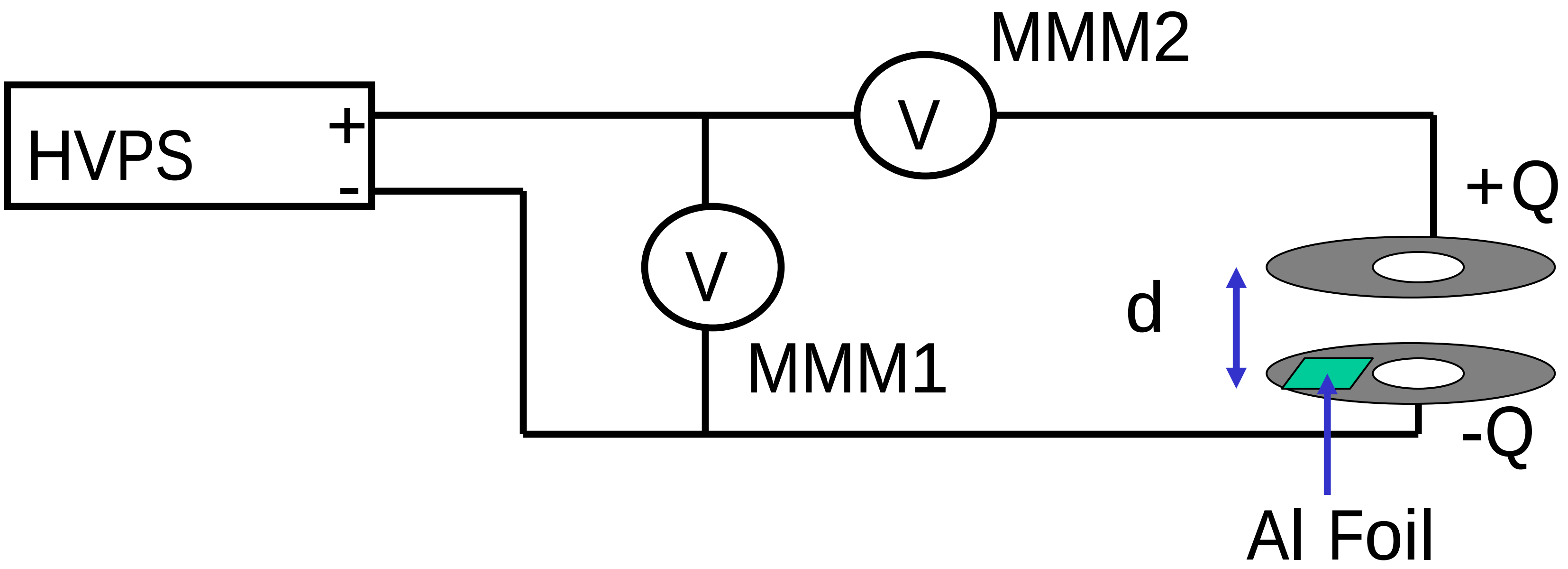
‘Puzzle’ Demo



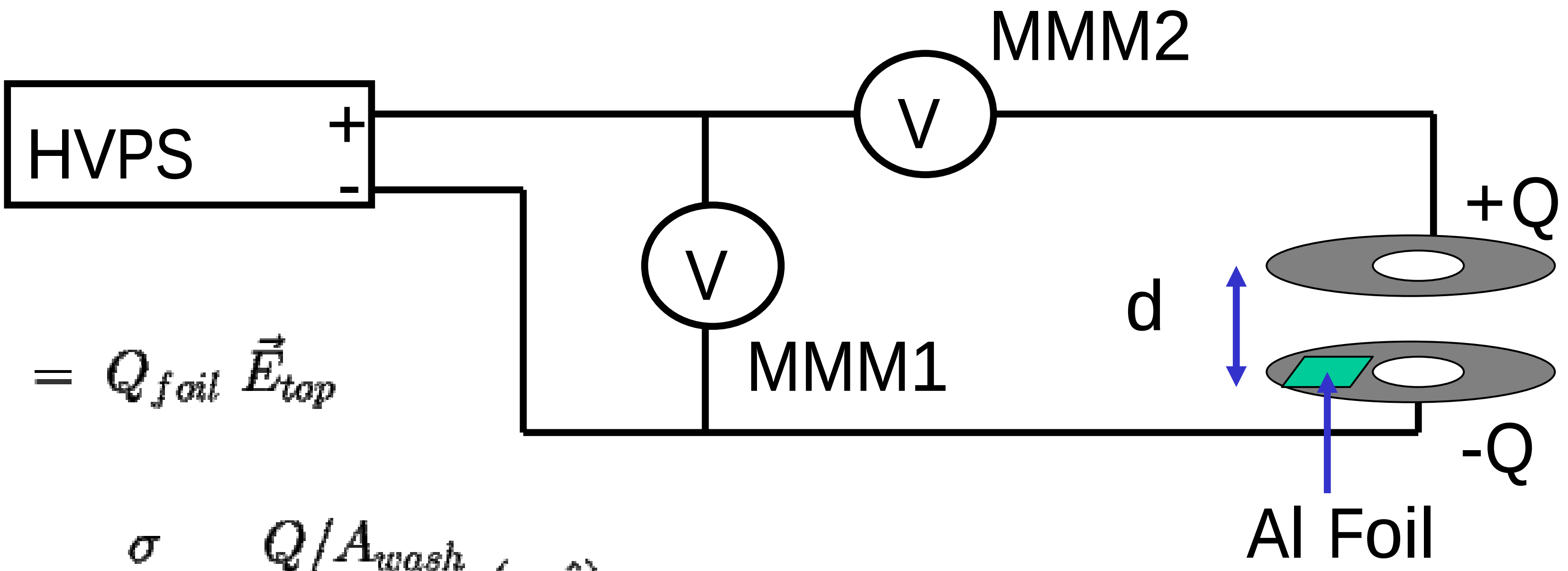
‘Puzzle’ Demo



Experiment EF



How do we measure ε_0 with this?



$$\vec{F}_{on\,foil} = Q_{foil}\,\vec{E}_{top}$$

$$\vec{E}_{top} = \frac{\sigma}{2\epsilon_0} = \frac{Q/A_{wash}}{2\epsilon_0}\,(-\hat{y})$$

$$Q_{foil} = -Q\frac{A_{foil}}{A_{wash}}$$

$$Q = CV = \varepsilon_0 A/d\ V$$

$$\Rightarrow \vec{F}_{on\,foil} = -Q\frac{A_{foil}}{A_{wash}}\,\frac{Q}{A_{wash}2\epsilon_0}(-\hat{y}) \qquad \Rightarrow \vec{F}_{on\,foil} = \frac{(\epsilon_0 V A_{wash}/d)^2}{A_{wash}^2}\,\frac{A_{foil}}{2\epsilon_0}\,\hat{y}$$

$$= \frac{Q^2}{A_{wash}^2}\,\frac{A_{foil}}{2\epsilon_0}\hat{y}$$

$$\boxed{= \frac{\epsilon_0 V^2}{2d^2}A_{foil}\,\hat{y}}$$

How to get force?

$$F_{on\,foil} = m_n g \quad \text{with} \quad m_N = \rho_m A_{foil} N t$$

t: thickness

$$\Rightarrow \frac{\epsilon_0 V^2}{2d^2} A_{foil} = \rho_m A_{foil} N t g$$

Balance unknown Force with known Force -> Gravity!

$$\Rightarrow \frac{\epsilon_0 V^2}{2d^2} = \rho_m N t g$$

$$\Rightarrow V^2 = \frac{2d^2 \rho_m t g}{\epsilon_0} N$$

$$= \text{slope} \cdot N$$

$$\Rightarrow \epsilon_0 = \frac{\rho_m 2d^2 t g}{\text{slope}}$$