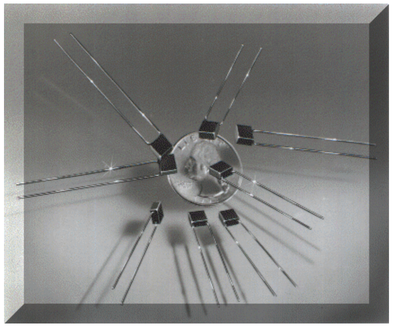
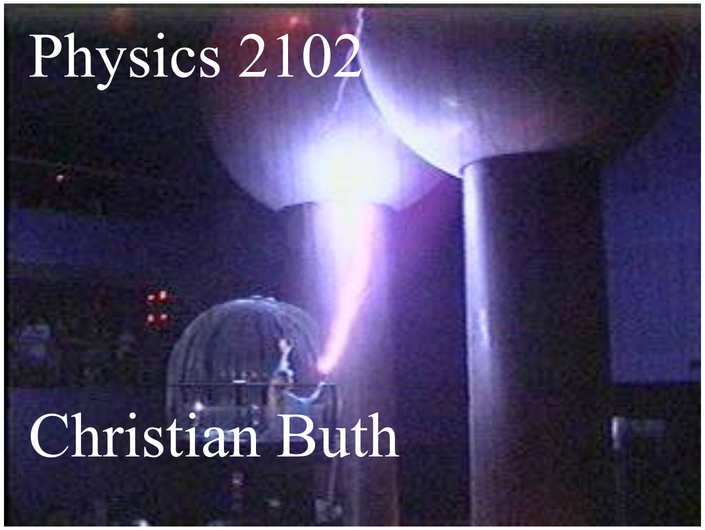
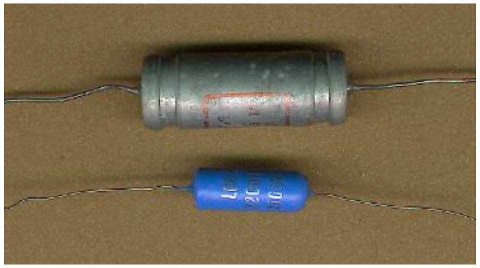




Physics 2102
Lecture 11
Capacitors 1

Version: 02/06/2009



Review

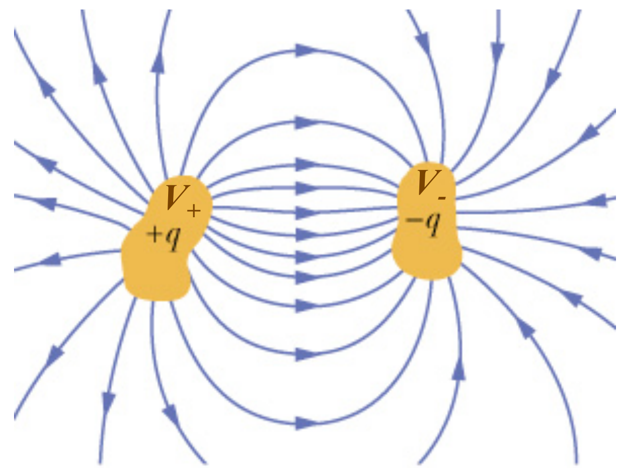
- **Electric potential energy**: work used to build the system, charge by charge:

$$U = \frac{1}{4\pi\varepsilon_0} \sum_{\substack{i,j=1 \\ i<j}}^{n} \frac{q_i q_j}{r_{ij}}$$

- Charges move to make surface of **conductors** equipotentials
- Thus conductors **change the field** around them!
- Charge density and electric field are higher on **sharp points** of conductor

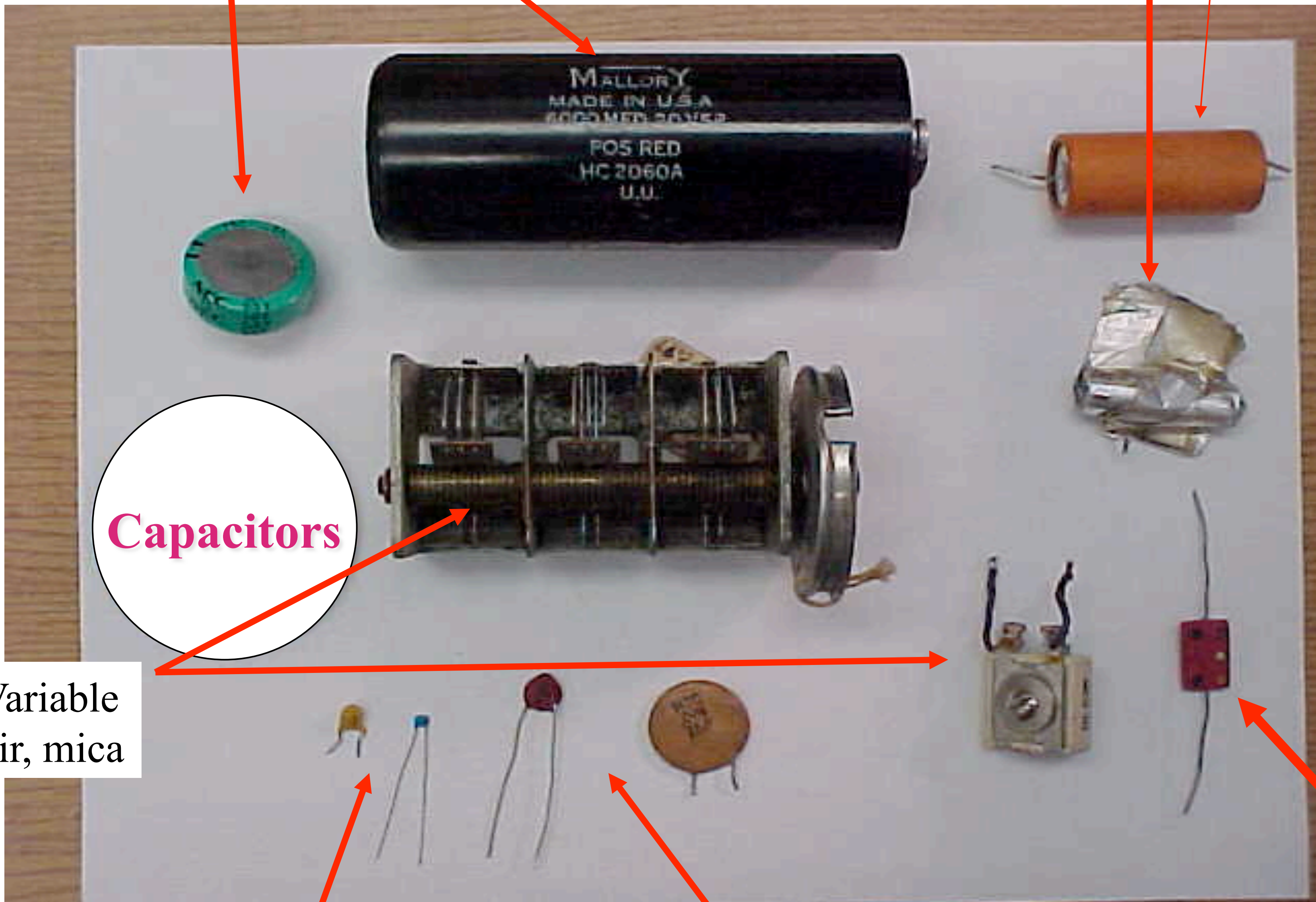
Capacitor

- **Use**: storing and releasing electric charge / energy
- **Capacitor**: any two conductors, one with charge $+Q$, other with charge $-Q$
- Potential difference between conductors: V



Electrolytic (1940-70)
Electrolytic (new)

Paper (1940-70)



Capacitors

Variable
air, mica

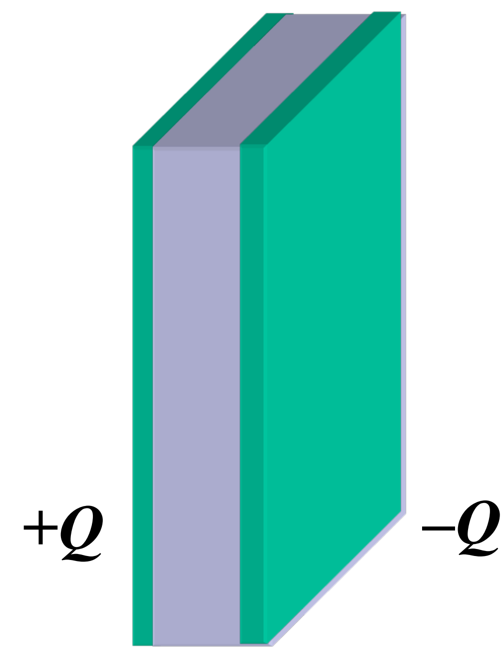
Tantalum (1980 on)

Ceramic (1930 on)

Mica
(1930-50)

Capacitance 1

- **Capacitance** quantifies the charge that can be stored in a capacitor
- Depends only on **geometrical** factors and the **material** between the two conductors
- e.g. Area of conductors, separation; space filled with air, plastic, etc.

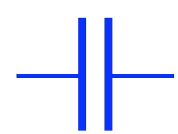


(We first focus on capacitors where gap is filled by **air**!)

Capacitance 2

- Potential difference between conductors: V, capacitance C of capacitor, charge Q on capacitor:

  $Q = \boldsymbol{C}V$

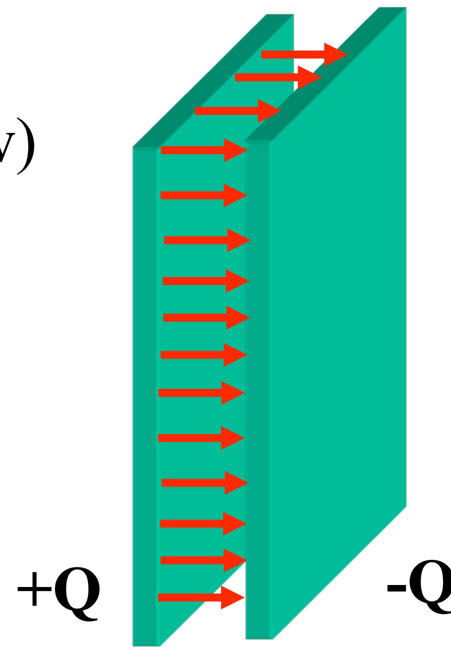
- **Unit of capacitance**: **Farad** (F) = Coulomb/Volt
- **Most** electronic capacitors:
  - micro-Farad (μF) — 10^{-6} F
  - nano-Farad (pF) — 10^{-9} F
  - pico-Farad (pF) — 10^{-12} F
- **New technology**: compact 1 F capacitors
- **Symbol** in electric circuit: 

Parallel Plate Capacitor

We want ***capacitance***: C=Q/V

E field between the plates: (Gauss' Law)

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}$$



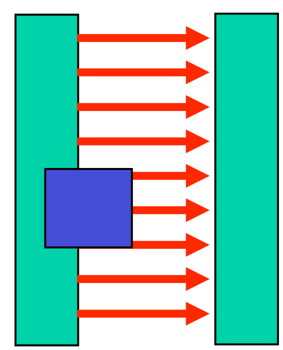
Area of each plate = A
Separation = d
charge/area = σ = Q/A

Relate E to potential difference V:

$$V = \int_0^d \vec{E} \cdot d\vec{x} = \int_0^d \frac{Q}{\varepsilon_0 A} dx = \frac{Qd}{\varepsilon_0 A}$$

What is the capacitance C?

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



Parallel Plate Capacitor — Example

- A huge parallel plate capacitor consists of two square metal plates of side 50 cm, separated by an air gap of 1 mm
- What is the capacitance?

$C = \varepsilon_0 A/d$

$= (8.85 \text{ x } 10^{-12}\ \text{F/m})(0.25\ \text{m}^2)/(0.001\ \text{m})$

$= 2.21 \text{ x } 10^{-9}\ \text{F}$

(Very Small!!)

Lesson: difficult to get large values of capacitance without special tricks!

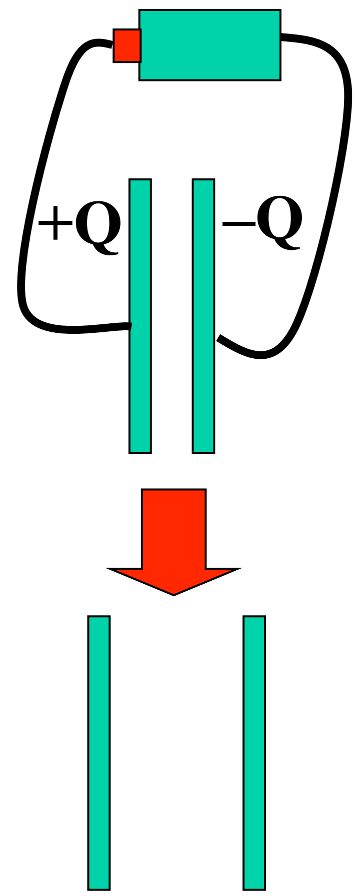
Isolated Parallel Plate Capacitor

- A parallel plate capacitor of capacitance C is **charged** using a battery
- Charge = Q, potential difference = V
- Battery is then **disconnected**
- If the plate separation is **increased**, does **potential difference** V:

(a) Increase

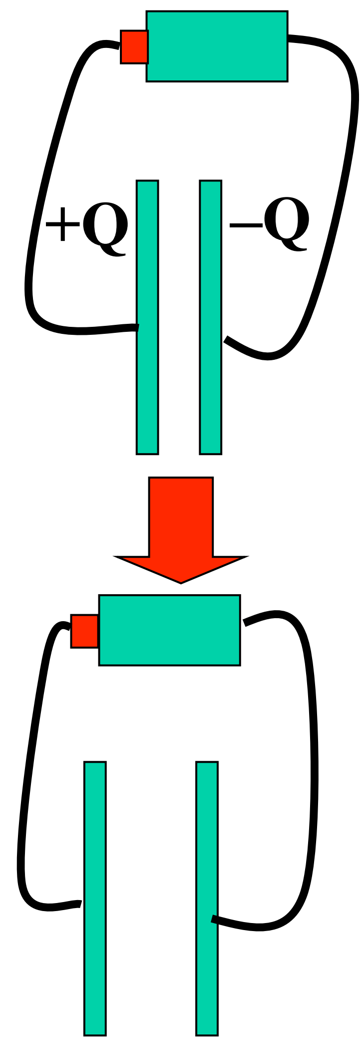
(b) Remain the san

(c) Decrease



Charging a Parallel Plate Capacitor

- A parallel plate capacitor of capacitance C is **charged** using a battery
- Charge = Q, potential difference = V
- Plate separation is **increased** while battery remains connected



Does the **electric field** Inside:

(a) Increase?

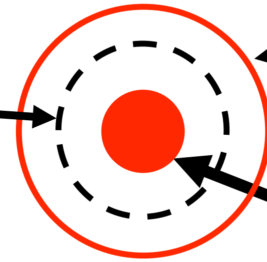
(b) Remain the Same?

(c) Decrease?

Spherical Capacitor

What is the electric field inside the capacitor? (Gauss' Law)

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$



Radius of outer plate = b

Radius of inner plate = a

Concentric spherical shells: Charge $+Q$ on inner shell, $-Q$ on outer shell

Relate E to potential difference between the plates:

$$V = -\int_b^a \vec{E} \cdot d\vec{s} = \int_a^b \frac{kQ}{r^2} dr = \left[-\frac{kQ}{r}\right]_a^b = kQ\left[\frac{1}{a} - \frac{1}{b}\right]$$

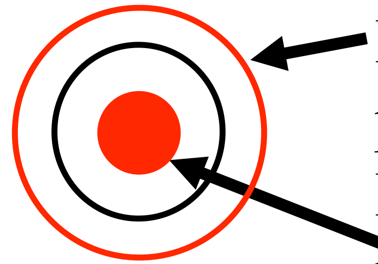
Spherical Capacitor

What is the capacitance?

$C = Q/V$

$$= \frac{Q}{\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{a} - \frac{1}{b}\right]}$$

$$= \frac{4\pi\varepsilon_0 ab}{(b-a)}$$

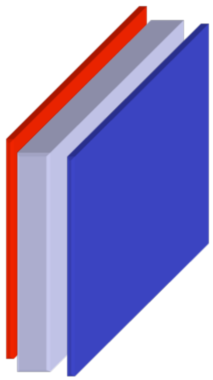


Concentric spherical shells:
Charge +*Q* on inner shell,
–*Q* on outer shell

Isolated sphere: let $b >> a$,

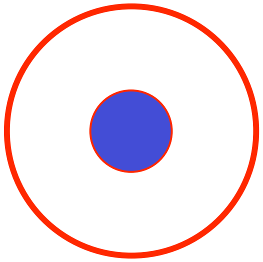
$$C = 4\pi\varepsilon_0 a$$

Summary



- Any two charged conductors form a **capacitor**
- **Capacitance**: $C = Q/V$
- Simple Capacitors:

Parallel plates: $C = \varepsilon_0 A/d$



Spherical: $C = 4\pi \varepsilon_0 ab/(b-a)$