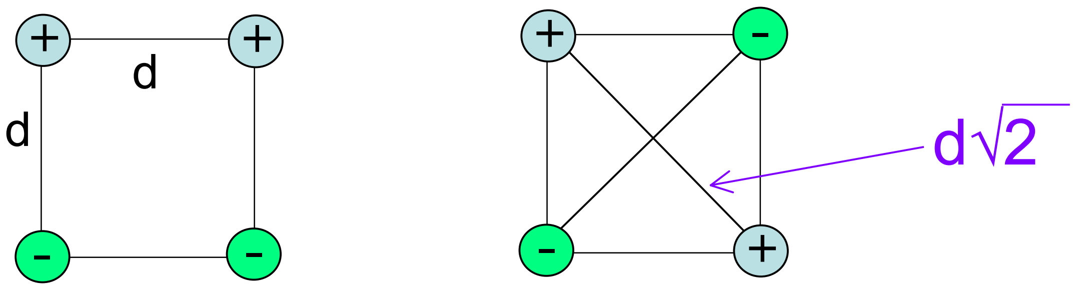
Which is more stable?

That is, which has the lower total P.E.?

(closer to –infty →more stable)

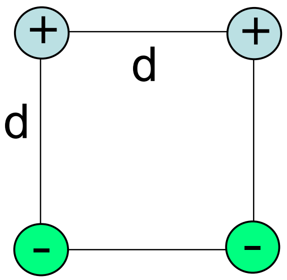


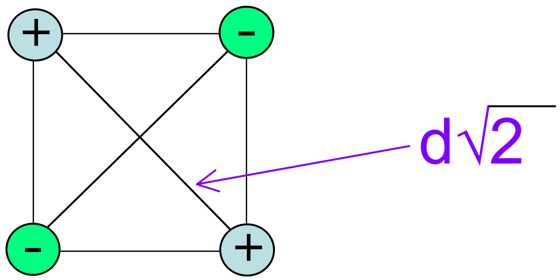
Total PE = PE of each side + PE of each diagonal

$PE_{side} = k_e q_1 q_2 / d$ *(pay attention to signs of charges!!!!)*

$PE_{diagonal} = k_e q_1 q_2 / (d\sqrt{2})$

Which is more stable?





Define $PE_0 = k_e q^2/d$

Sides: PE_0	+2 -2	-4
Diag.: $PE_0/\sqrt{2}$	-2	+2
Total PE	$(-2/\sqrt{2})\ PE_0 = -1.41PE_0$	$(-4 + 2/\sqrt{2})PE_0 = -2.59PE_0$

Yes, this
distribution is
stable….

… but this one is
MORE stable!

The Size of Atomic Nuclei

Ernest Rutherford et al.'s scattering experiments, 1911

Goal: Probe structure of atoms: How are the + and – charges distributed, and what's their size?

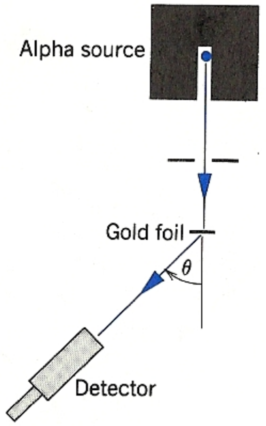


Figure 1 The experimental arrangement used in Rutherford's laboratory to study the scattering of α particles by thin metal foils. The detector can be rotated to various scattering angles θ.

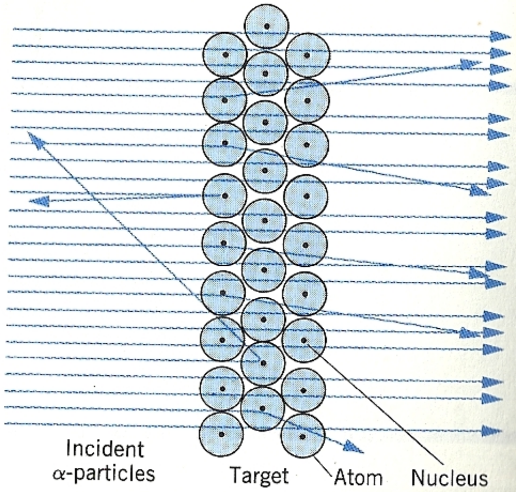


Figure 3 The angle through which an α particle is scattered depends on how close its extended incident path lies to the nucleus of an atom. Large deflections result only from very close encounters.

Method: Fire positively charged alpha-particles (ionized He nuclei, Z=2) at a very thin metal (Au, Z=79) foil
Most passed through, but a few were deflected through large angles--including up to 180º!
(ch. 29)

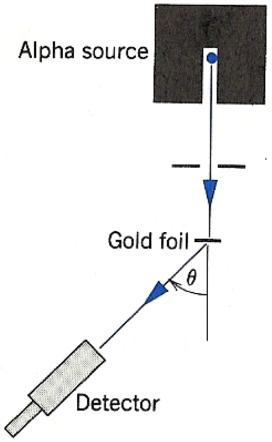


Figure 1 The experimental arrangement used in Rutherford's laboratory to study the scattering of α particles by thin metal foils. The detector can be rotated to various scattering angles θ.

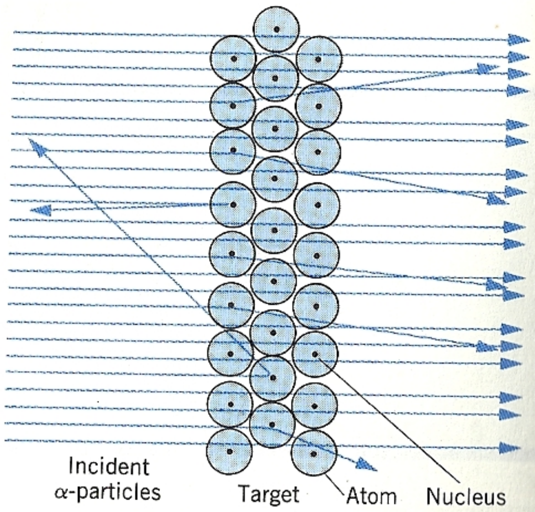
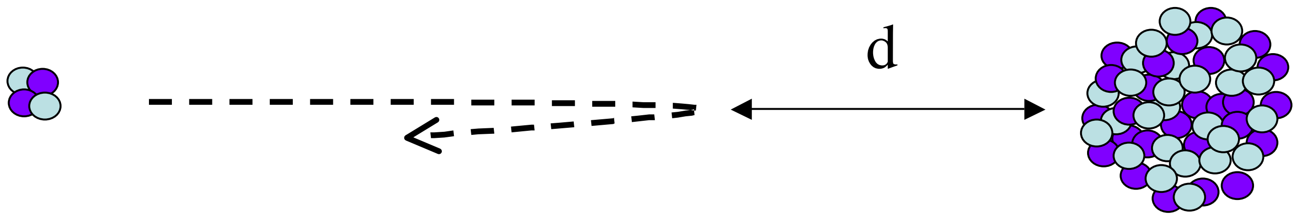
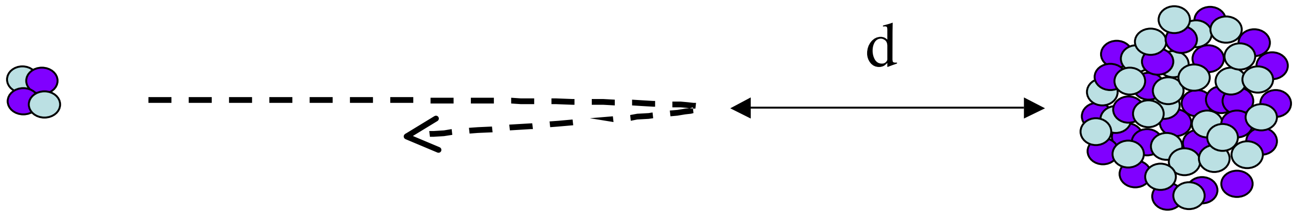


Figure 3 The angle through which an α particle is scattered depends on how close its extended incident path lies to the nucleus of an atom. Large deflections result only from very close encounters.



An alpha particle (He^{2+} = 2p + 2n, total mass = $4*1.67*10^{-27}$ kg) is fired at v= $1.0x10^{7}$ m/s and happens to be headed directly for the nucleus of a gold atom (79 p) at rest. How close does it get to the gold nucleus before the electric force brings it to a momentary stop and reverses its course? Neglect the recoil of the Au nucleus; neglect the Au atom's electrons.

The Size of Atomic Nuclei



Initially, total energy = K.E. of He^{+2} (P.E. = zero since $d = \infty$)

At closest interaction, total energy = P.E. = $k_e Q_1 Q_2 / d$

$d = k_e Q_1 Q_2 / K.E.$

K.E. = $1/2\, m_{He} v^2 = 1/2\, (4*1.67\times10^{-27}\text{kg})(1\times10^{7}\text{m/s})^2 = 3.3\times10^{-13}$ J

$d = (9\times10^{9}\ \text{Nm}^2/\text{C}^2)(2)(79)(1.6\times10^{-19}\text{C})^2 / (3.3\times10^{-13}\text{J}) = 1.1\times10^{-13}$ m = 110 fm

Size of nucleus must be smaller than this -- VERY compact compared to size of atom ($\sim10^{-11}$ m)

110 fm is small by atomic standards, but not by nuclear standards

Ch. 20.4

Obtaining the Electric Field from the Potential:

What do we do if V is function of position in space, described as V(x,y,z)?

First, consider the case where the E-field has only one component:

$$\Delta V = -\vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$$

$$-\vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} \text{ becomes } -E_x dx \text{ and } E_x = -\frac{dV}{dx}$$

Given V (x, y, z) you can find E_x, E_y and E_z as partial derivatives:

$$E_x = -\frac{\partial V}{\partial x} \quad E_y = -\frac{\partial V}{\partial y} \quad E_z = -\frac{\partial V}{\partial z}$$

Example: Suppose you have a 2-D potential quantified as $V(x,y) = Ax + By$

(A,B = some constants)

(two pairs of oppositely-charged parallel plates, arranged so that each one's E-fields are perp.)

$E_x = -dV/dx = -A$

$E_y = -dV/dy = -B$

(potential increases as one goes towards +x and/or +y -- that means you're getting closer to the positively-charged plates)

If the charge distribution and electric field both have spherical symmetry, $dV = -E_r dr$

$E_r = -dV/dr$

Ex.: a point charge:

$V = k_e q/r$

$E_r = -(dV/dr) = -(-k_e q/r^2) = k_e q/r^2$

Ch. 20.5

How to calculate V due to a continuous charge distribution (most general form)

Ch. 20.6: V of a charged conductor

Recall: excess charge resides on the suface,
while inside, the E-field is zero.

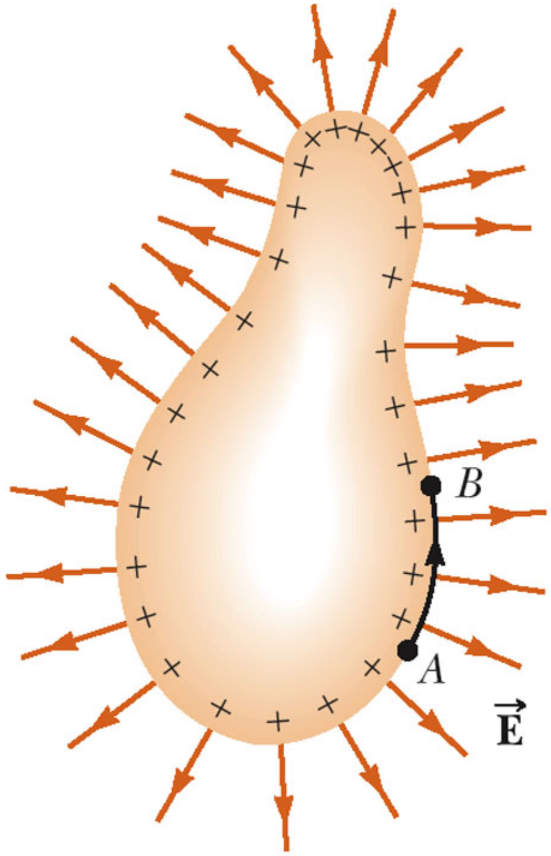
Surface of a Charged Conductor

Potential is same at all points on conductor's surface

E-field is ⊥ to surface at all points

No net work required to move a charge along surface

$W = -\Delta U$
$\Delta U = q(V_b - V_a)$
If $V_a = V_b$, then $W = 0$!



Interior of a Charged Conductor

At all points inside a conductor, the potential is constant and the same as at the surface

Reminder: E = 0 inside the conductor

$\Delta V = Ed = 0d$

So V must be constant

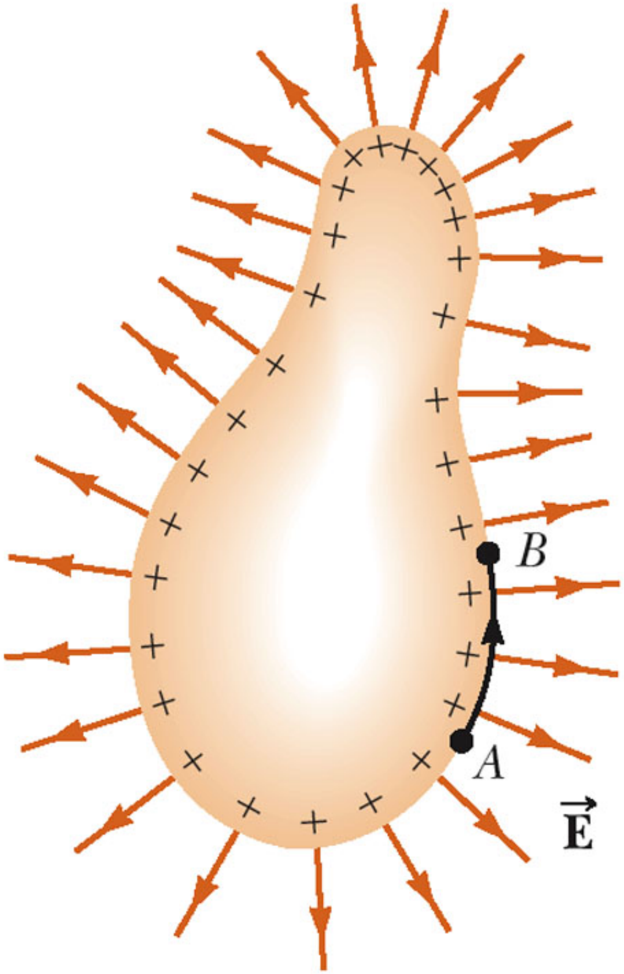
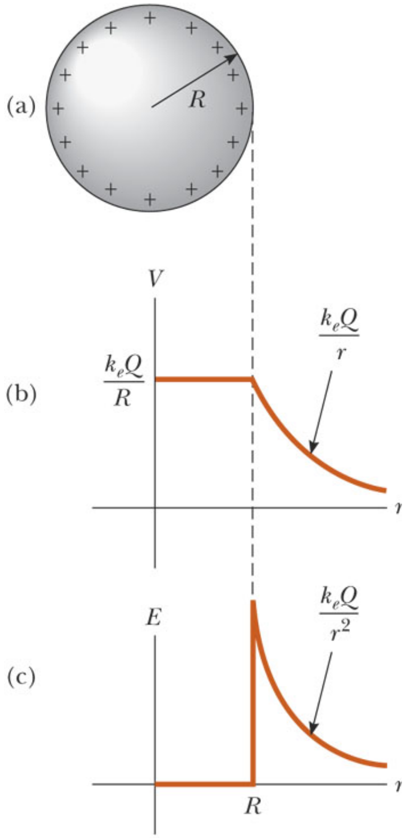
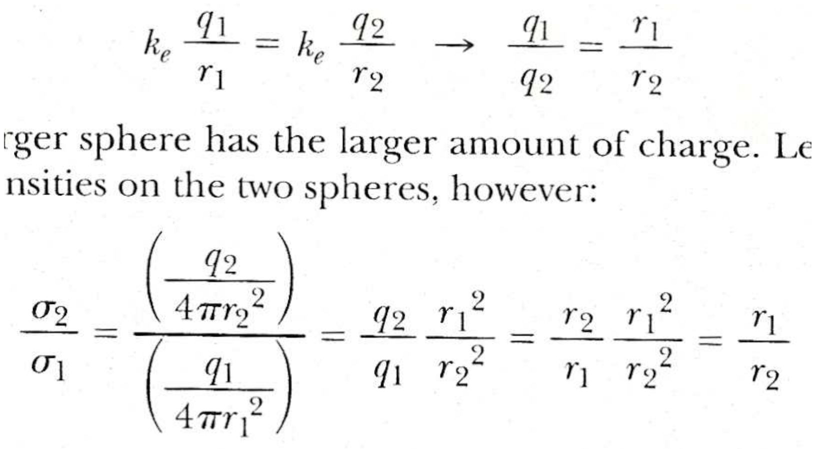


Figure 20.14:



Irregularly-shaped objects: Fig 20.15

All surface points must be at same potential

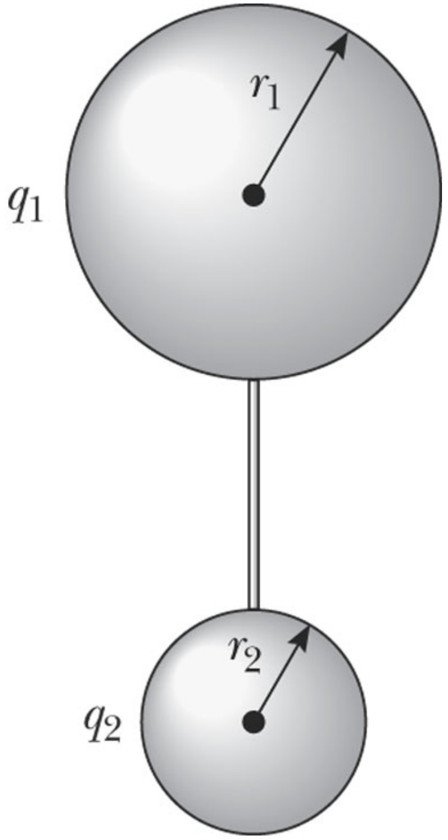


$$k_e \frac{q_1}{r_1} = k_e \frac{q_2}{r_2} \quad \rightarrow \quad \frac{q_1}{q_2} = \frac{r_1}{r_2}$$

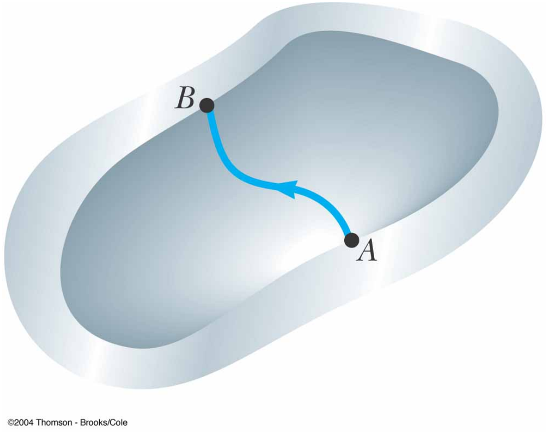
rger sphere has the larger amount of charge. Le
nsities on the two spheres, however:

$$\frac{\sigma_2}{\sigma_1} = \frac{\left(\dfrac{q_2}{4\pi {r_2}^2}\right)}{\left(\dfrac{q_1}{4\pi {r_1}^2}\right)} = \frac{q_2}{q_1}\frac{{r_1}^2}{{r_2}^2} = \frac{r_2}{r_1}\frac{{r_1}^2}{{r_2}^2} = \frac{r_1}{r_2}$$

Smaller radius of curvature = higher surface density of charge



Charge-free cavity inside a conductor



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The electric field inside the conductor is must be zero and does not depend on the charge distribution on the outside surface of the conductor For all paths between A and B, ΔV =

$$V_B - V_A = -\int \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = 0$$

A cavity surrounded by conducting walls is a field-free region as long as no charges are inside the cavity

Thunderstorms:

From ground to cloud base:
$\Delta V \sim 10^{7\text{-}8}$ V, $E \sim 10^{4\text{-}5}$ V/m

Lightning: $E = 3\times10^{6}$ V/m is electric field strength at which air becomes ionized enough to act as a conductor.

Fair weather: $E \sim 10^{2}$ V/m

Batteries

- **Offer constant potential difference ΔV,** yielding a steady amount of charge through relatively slow chemical reactions.

- Electrons flow from the negative terminal to the positive terminal.
- Reaction doesn't take place unless the terminals are connected to something (so batt. can sit on shelf for a while and still have lots of power)
- If you attach a wire between the terminals directly, with no load, you'll wear out the battery quickly.

Parts of a battery

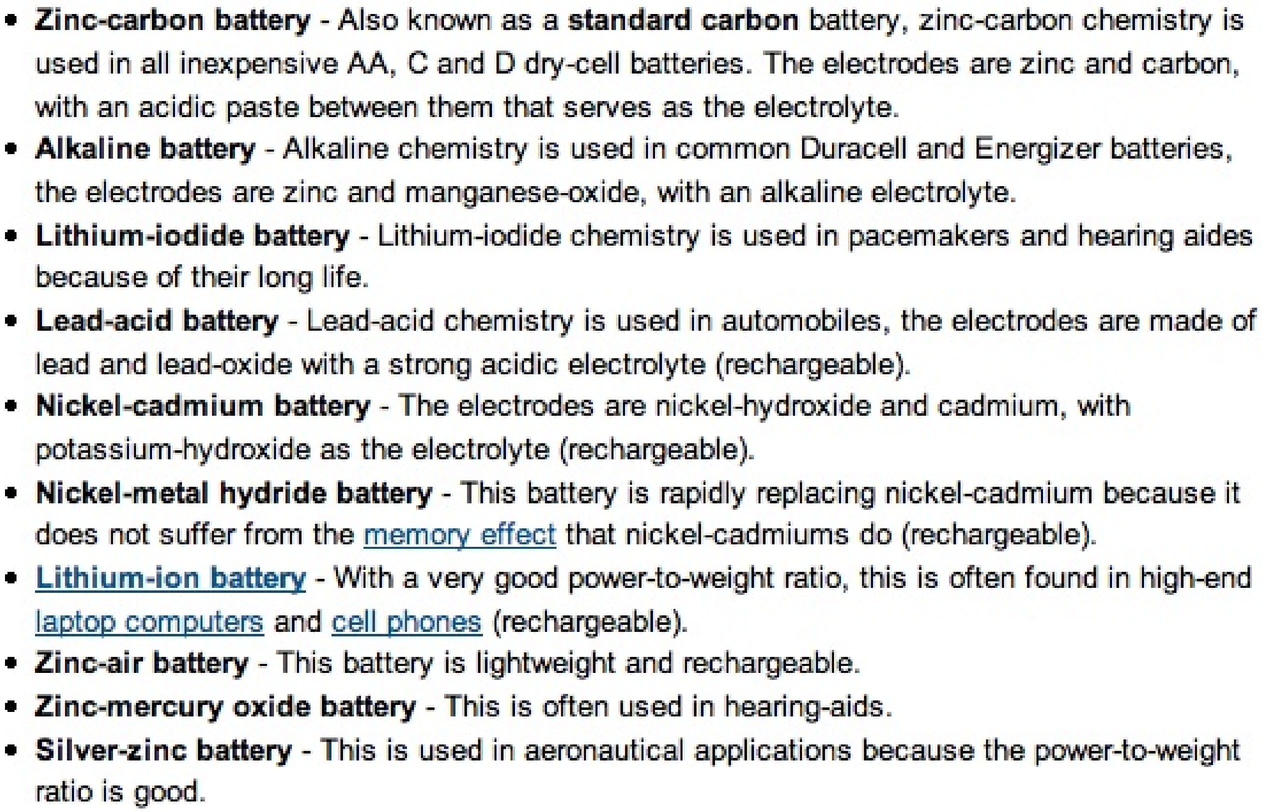
Example: Zn/C battery:
Negative terminal: Zn
Positive terminal: C
Electrolyte: sulfuric acid
conducting wire

$H_2SO_4 + Zn \rightarrow \quad SO_4^{-} + H^{+} + H^{+} + Zn^{2+} + e^{-} + e^{-}$

$Zn^{2+} + SO_4^{-} \rightarrow ZnSO_4$

The e^{-}'s from the zinc atoms flow through the wire and combine with H on the Carbon rod. (lower potential V: easier then combining with the H^{+} in the acid)

Different combinations of metals and electrolytes (medium) control the final voltage



- **Zinc-carbon battery** - Also known as a **standard carbon** battery, zinc-carbon chemistry is used in all inexpensive AA, C and D dry-cell batteries. The electrodes are zinc and carbon, with an acidic paste between them that serves as the electrolyte.
- **Alkaline battery** - Alkaline chemistry is used in common Duracell and Energizer batteries, the electrodes are zinc and manganese-oxide, with an alkaline electrolyte.
- **Lithium-iodide battery** - Lithium-iodide chemistry is used in pacemakers and hearing aides because of their long life.
- **Lead-acid battery** - Lead-acid chemistry is used in automobiles, the electrodes are made of lead and lead-oxide with a strong acidic electrolyte (rechargeable).
- **Nickel-cadmium battery** - The electrodes are nickel-hydroxide and cadmium, with potassium-hydroxide as the electrolyte (rechargeable).
- **Nickel-metal hydride battery** - This battery is rapidly replacing nickel-cadmium because it does not suffer from the memory effect that nickel-cadmiums do (rechargeable).
- **Lithium-ion battery** - With a very good power-to-weight ratio, this is often found in high-end laptop computers and cell phones (rechargeable).
- **Zinc-air battery** - This battery is lightweight and rechargeable.
- **Zinc-mercury oxide battery** - This is often used in hearing-aids.
- **Silver-zinc battery** - This is used in aeronautical applications because the power-to-weight ratio is good.

(http://electronics.howstuffworks.com/battery.htm)

Lemon Battery

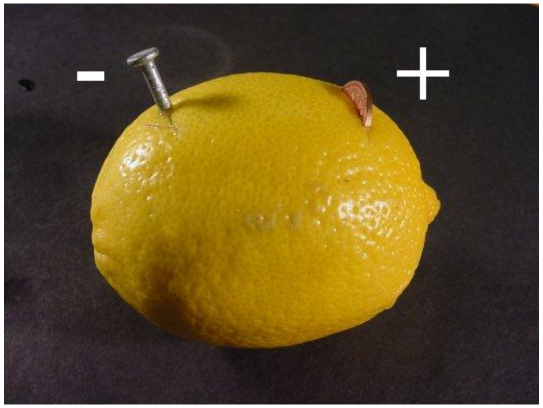
http://hilaroad.com/camp/projects/lemon/lemon_battery.html
http://www.ehow.com/how-does_5474935_lemon-battery-works.html

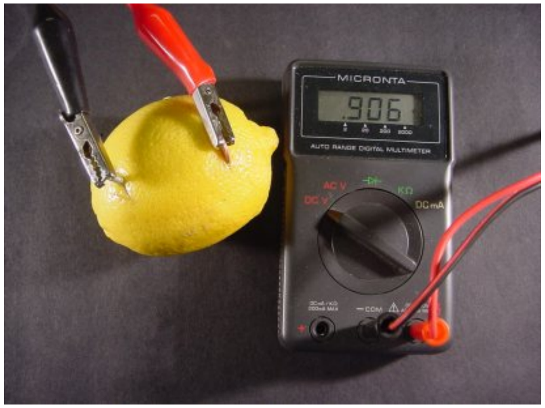
Lemons contain citric acid (electrolyte)
Negative terminal: Galvanized nail (Zn coating)
Positive terminal: Cu penny

$Zn \rightarrow Zn^{2+} + 2\ e^{-}$

The copper attracts the electrons

When the electrons reach the other end:
$2H^{+} + 2e^{-} \rightarrow H_2$





http://amctv.com

http://www.scriptphd.com

Walt uses everyday materials to build a homemade Galvanic Cell.

Anode (neg.): Zn from coins, galvanized nuts, bolts, washers

Cathode (pos.): graphite + mercuric oxide from the RV’s brake pads

Electrolyte: sponge in potassium hydroxide: (supply K+ and OH- ions)

Conductor: Cu wire

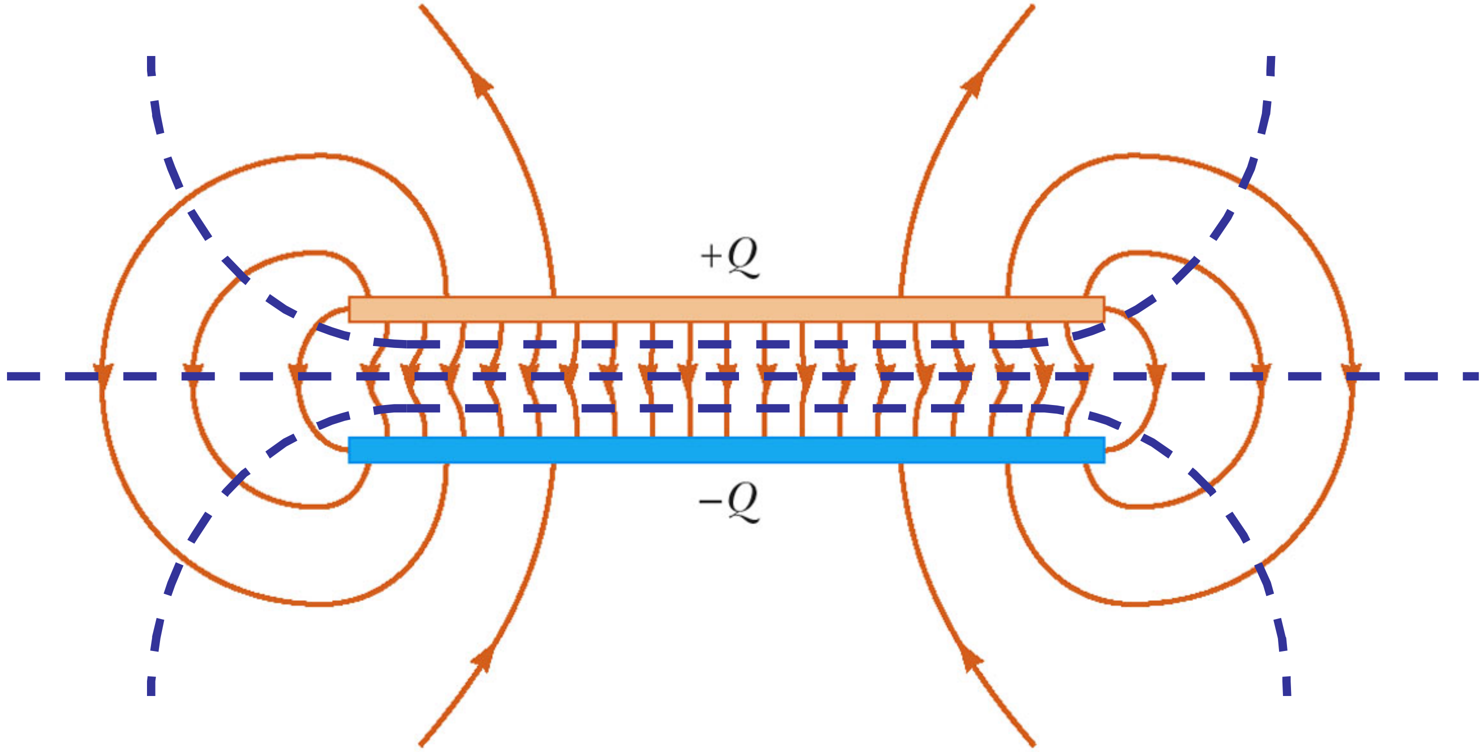
Connecting cells in series

$\Delta V_{total} = \Delta V_1 + \Delta V_2 + \ldots + \Delta V_6$

$9V = 1.5V + 1.5V + \ldots. + 1.5V$

2 Charged Planes

Equipotential surfaces are parallel to the planes and ⊥ to the E-field lines



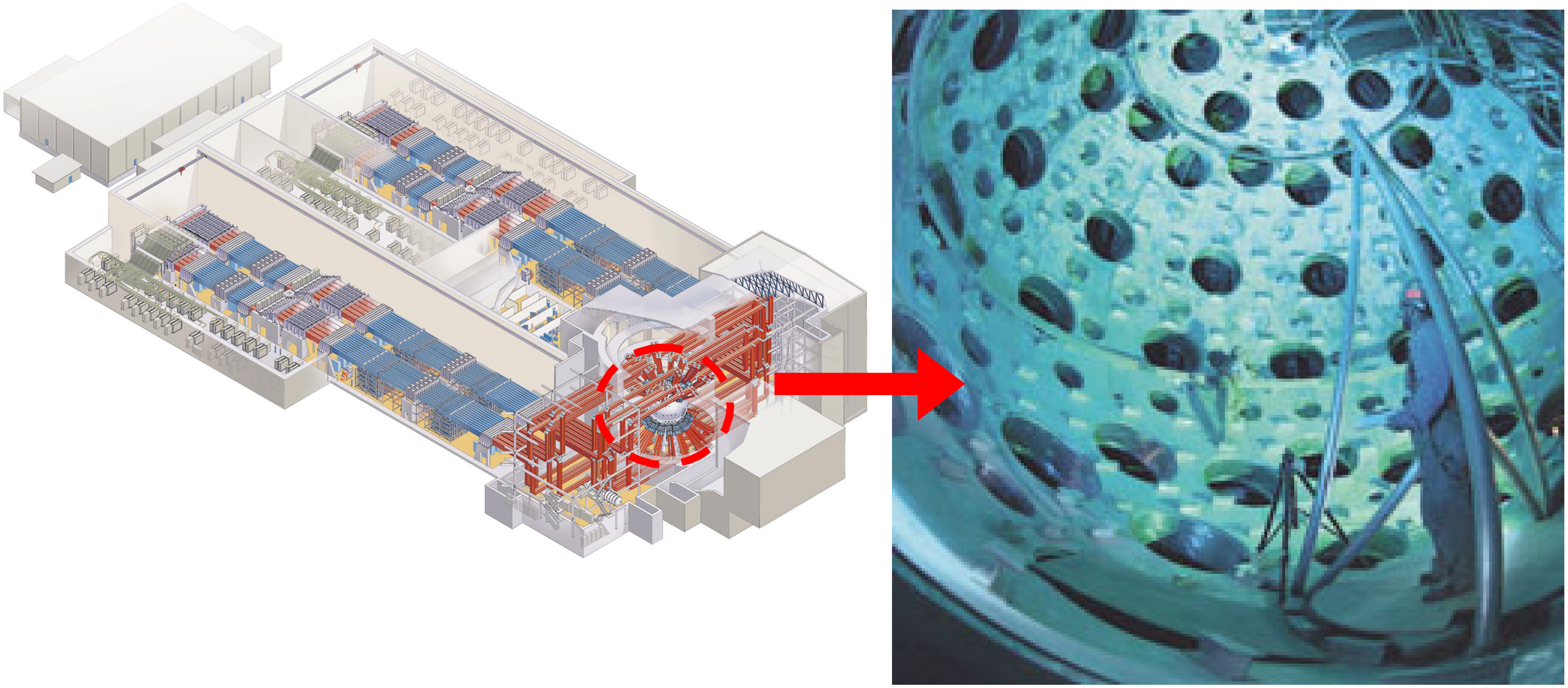
Capacitors & Capacitance

Capacitor: a device for storing electrical potential energy

Can also be rapidly discharged to release a large amount of energy at once

Applications: camera flashes, automobile ignition systems, computer memory, laser flash lamps, defibrillators

Laser Fusion at the Nat'l Ignition Facility, Livermore, CA. 10^6 J released in μs: Power ~ 10^{12} W

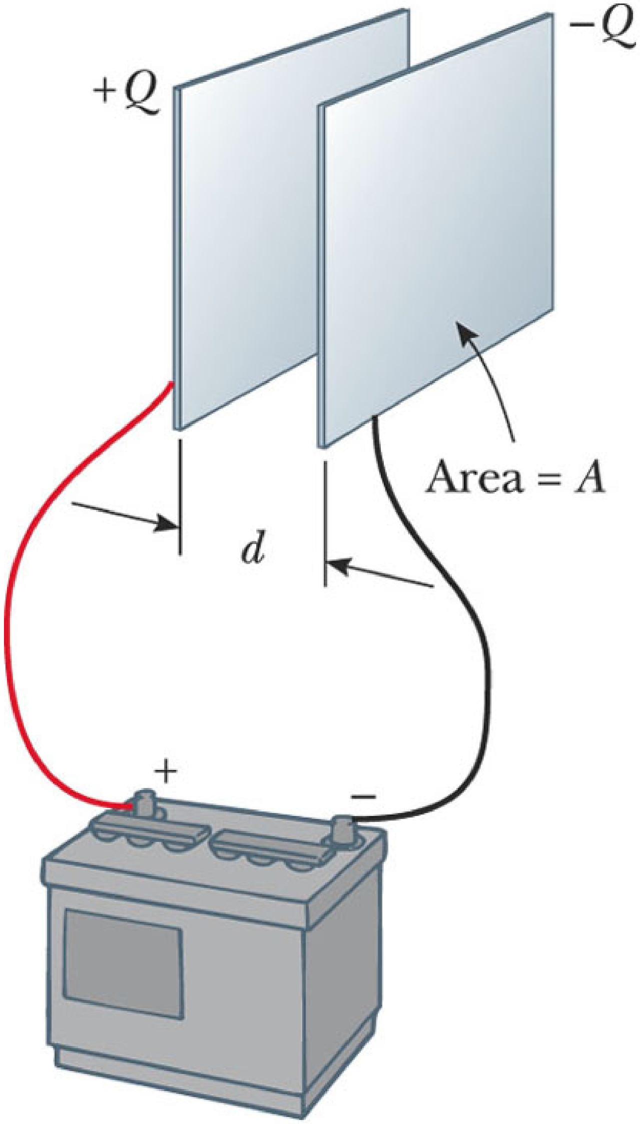


Credit:: LLNL

- A discharging capacitor delivers a large quantity of charge at once (if current is unregulated by resistors -- to be discussed in ch 21)
- Batteries: Offer constant potential difference ΔV, yielding a steady amount of charge through relatively slow chemical reactions.

.68 MFD
200 VDC
3,500 μF
40 VDC
MADE IN U.S.A.
POS +
MAX SURGE 250VDC
330V 1300μF

A Capacitor



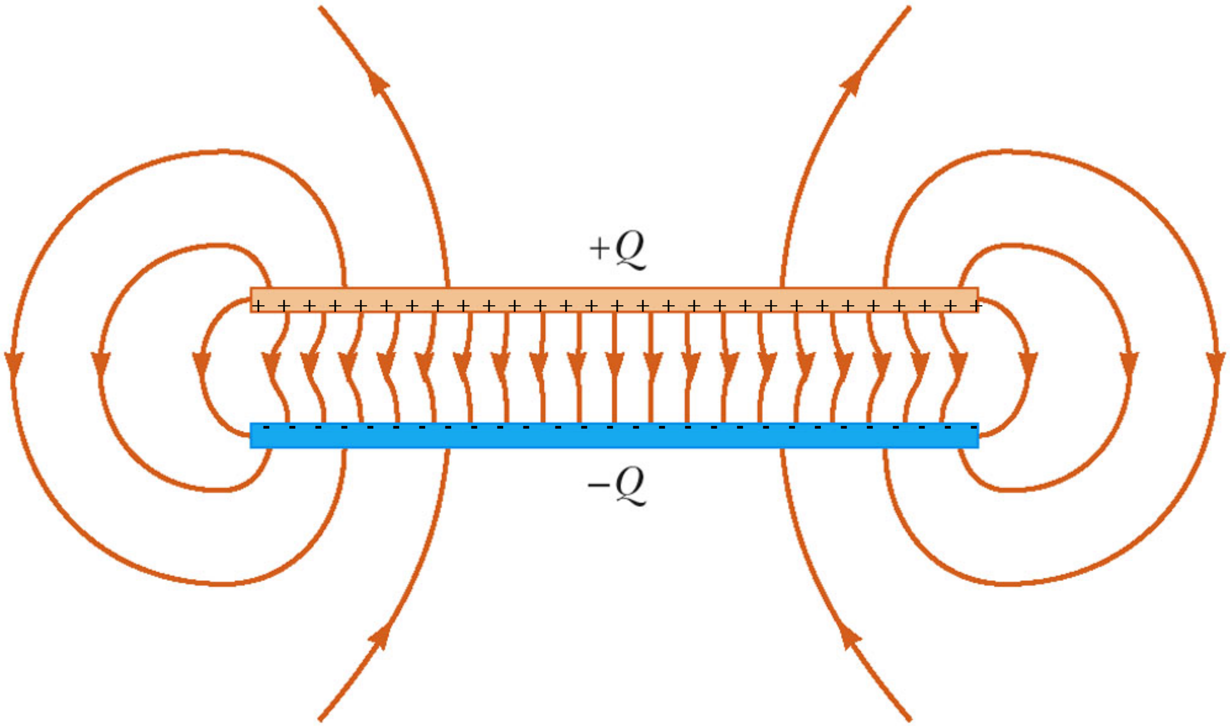
Note: +Q plate is connected to positive terminal of battery; –Q plate connected to – terminal.

Capacitance is defined as the ability to store separated charge.

$C = Q / \Delta V$

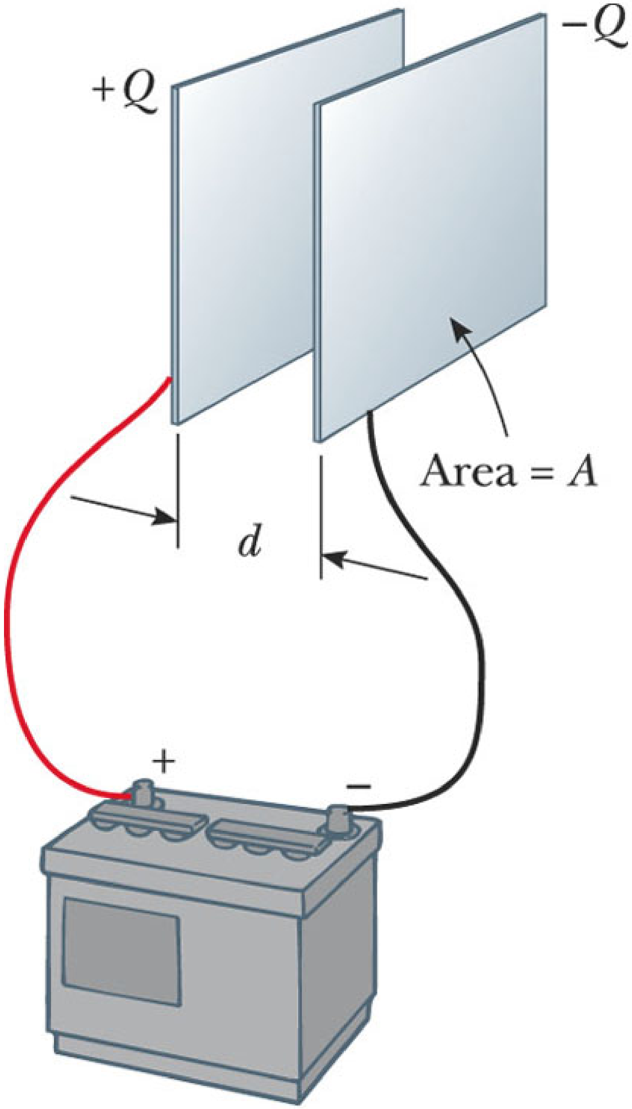
Unit: FARAD = C/V

Parallel Plate Capacitor



Note E-field inside is pretty uniform. E-field outside is relatively negligible

Charges like to accumulate at inner edges of plates



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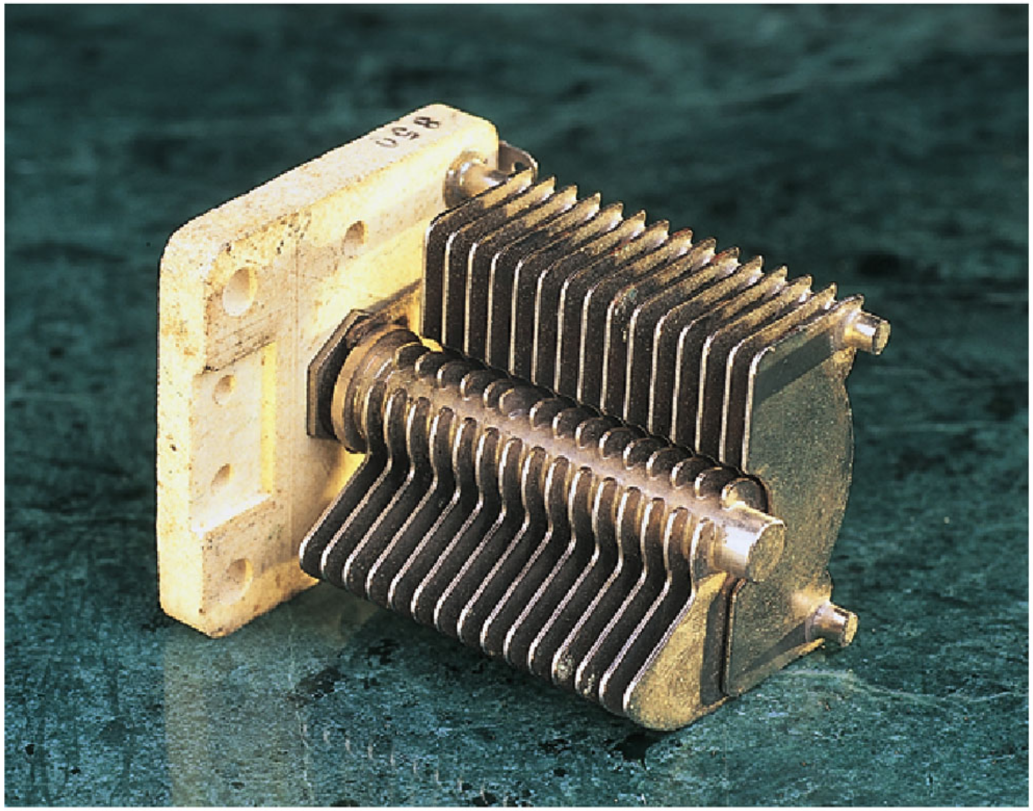
Parallel Plate Capacitor

Capacitance depends on geometry:

$$\mathbf{C = \varepsilon_0 A / d}$$



Variable capacitor: C depends on "overlapping" area

Example:

A parallel-plate capacitor with A = 4 cm^2, d = 1 mm. Find its capacitance.

$C = \varepsilon_o A/d = (8.85\text{x}10^{-12}\ C^2/Nm^2)(4\text{x}10^{-4}\ m^2)/(10^{-3}\ m)$
$= 3.54\text{x}10^{-12}\ F = 3.54pF$

If the capacitor is connected to a 9 Volt battery, how much charge is on each plate?

$C = Q/\Delta V \rightarrow Q = C\Delta V = (3.54\text{x}10^{-12}\ F)(9V)$
$=3.2\text{x}10^{-11}\ C$

Calculate the charge density on one plate (assume uniform distribution).

$\sigma = Q/A = 3.2\text{x}10^{-11}\text{ C} / 4\text{x}10^{-4}\text{ m}^2 = 8\text{x}10^{-8}\text{ C/m}^2$

Calculate the magnitude of the E-field inside the capacitor.

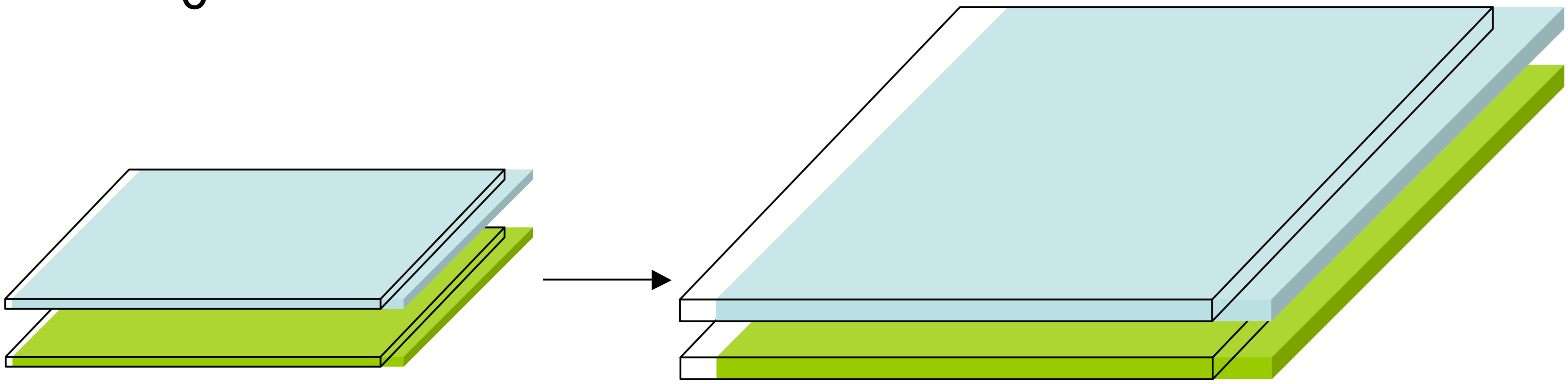
$E = \sigma/\varepsilon_0 = (8\text{x}10^{-8}\text{ C/m}^2)/(8.85\text{x}10^{-12}\text{ C}^2/\text{Nm}^2)$

$= 9000\text{ N/C}$

Double the area…

A → 2A:

$C = \varepsilon_0 A/d$



C→ 2C

… you double the capacitance!