Real-life Capacitors → Dielectrics

A parallel-plate capacitor $C = \frac{\varepsilon_0 A}{d}$

Example 18.6 → 10 mm × 10 mm plates, $d = 10\,\mu m$ → 90 pF
human hair! pico $= 10^{-12}$

Q: why is the capacitance $\sim \frac{1}{d}$?

another way to phrase it: given ΔV_B, and plates of area A,

- why can we displace more charge Q when d is small?

Answer: we derived the energy stored in the $\vec{E}$ field of a capacitor by calculating the work required to displace an extra charge ΔQ, i.e., to go from Q_0 to $Q_0 + \Delta Q$.

To place charge on a plate the battery has to fight the repulsion between like-charges.

If the opposite plate is at a smaller distance d, the repulsions from like charges are somewhat cancelled by attractions to the opposite charges on the opposite plate (and vice versa).

There is a practical limit to reducing d in order to obtain bigger capacitances C.

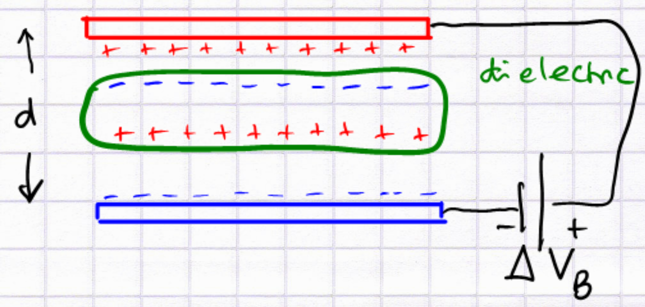
→ sparking → discharge

→ put an insulating sheet in between → paper / glass / glycerine

insulator = dielectric polarizes when charge Q is displaced.

The dielectric polarizes → creates an opposing $\vec{E}$ field

→ much more charge Q can be put on plates than before!



We describe the new situation by almost the same eqn:

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

but define $\varepsilon_0 \to K\varepsilon_0$; K = dimensionless dielectric constant

$K > 1$

$\downarrow$

$K_{air} = 1.0006$, $K_{paper} \sim 4$, special materials ~ 200 or more

$$C \to \frac{K\varepsilon_0 A}{d}$$

(generalized from vacuum parallel-plate cap.)

The best dielectrics do not just involve polarization of dipoles, but transport of ions to the surfaces

When the outside field is turned off (C is discharged)
→ the polarization of the dielectric turns off.

There are special materials which retain their polarization, and which can be used for computer memory (ferroelectrics)

↳ they also display the piezoelectric effect
(pressure applied → electric surface charge appears)

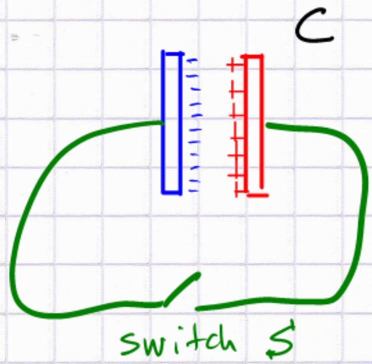
→ ultrasound detection devices
ultrasensitive microphones (electret condenser)

→ connection to liquid crystals → LCD displays

Dielectrics allow one to manufacture capacitors for electronics that are small in volume, yet can have nanofarad → microfarad capacitances. For millifarad capacitances one uses electrolytes. New materials allow to construct "super-capacitors" (multiple farads) for battery back up / boost in digital cameras and also in the automotive sector (hybrids!)

Simple Circuit → electric current

Suppose we have a charged capacitor



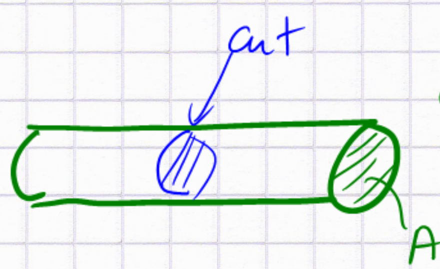
with C replaced by a battery this is an illegal (dangerous) circuit!

What happens when we close the switch S ?

We expect the charge to equilibrate: electrons from the ⊖ plate push into the copper wire; conduction electrons inside the copper wire travel a tiny amount (from ⊖ to ⊕), and some e^- are pushed onto the ⊕ plate.

Thus, $Q(t) \to 0$, where Q is the +/- charge on either plate.

Particle current:



copper wire, cross sectional area A

How many particles (charges) flow through A per unit time

Charge current: $i \equiv \frac{\Delta q}{\Delta t}$ ← can't be constant in our example

unit: $\frac{C}{s}$ → ampère

positive charge moving R → L or negative moving L → R
≡ same thing

Conduction in metals: conduction electrons move

" in ionic solutions: positive ions move

$+ \rightarrow -$

negative ions move

$- \rightarrow +$

Example 19.1 explains how many electrons flow through the cross section of a wire per second for a current of 0.5A

→ typical current for → light bulb (60 Watts / 120 Volts)

→ car sound system @ 12 Volts delivering a few watts of audio

$N = 10^{22}$ electrons/sec.

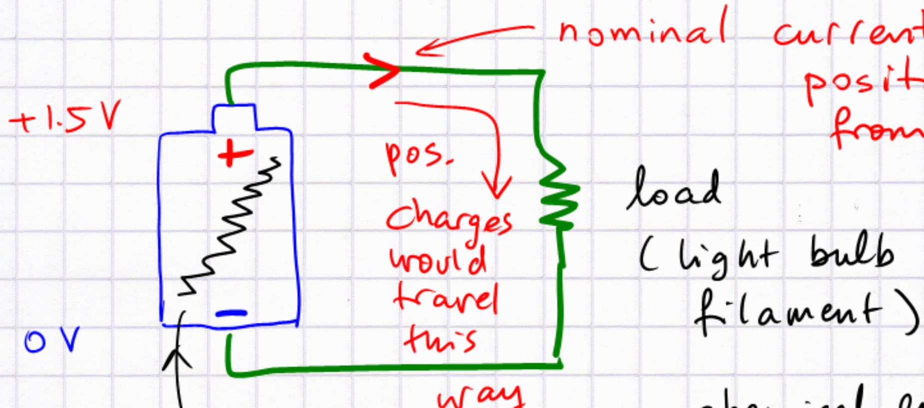
What is a battery?

A capacitor under discharge can drive a current through a wire only for a short time

A battery is capable of pushing a current through the wire for a long time and quite continuously. It acts like an escalator!

nominal current direction (like $\vec{E}$ field)

positive charges are pushed from + to −



Reality: e^-s flow from − to +.

escalator model: chemical energy inside the battery transports pos. ions to high PE (+)