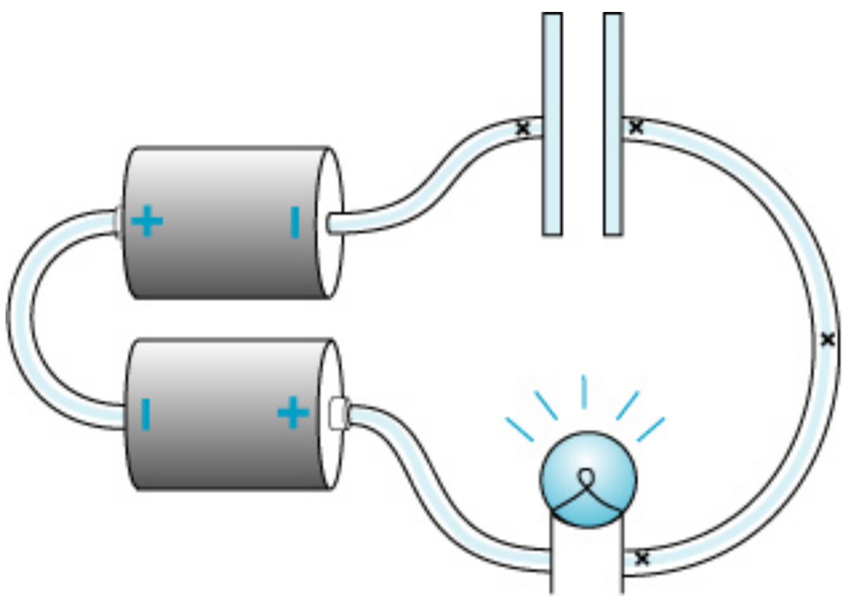
Chapter 19

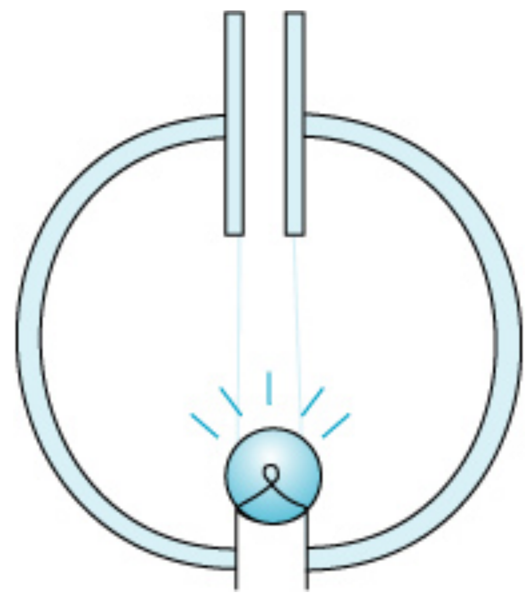
Capacitors, Resistors and Batteries

Capacitor: Charging and Discharging

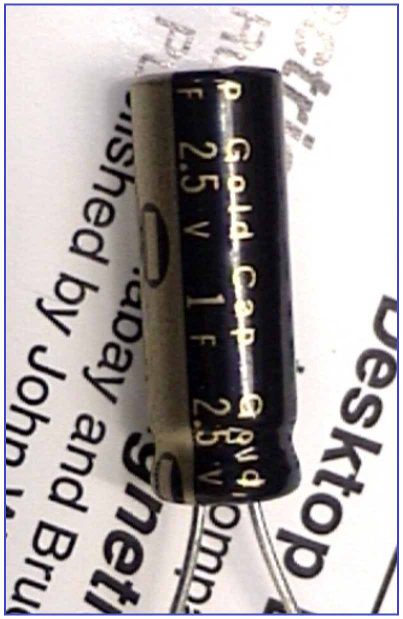
Experiment 1



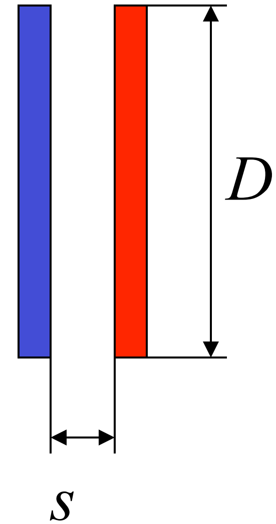
Experiment 2



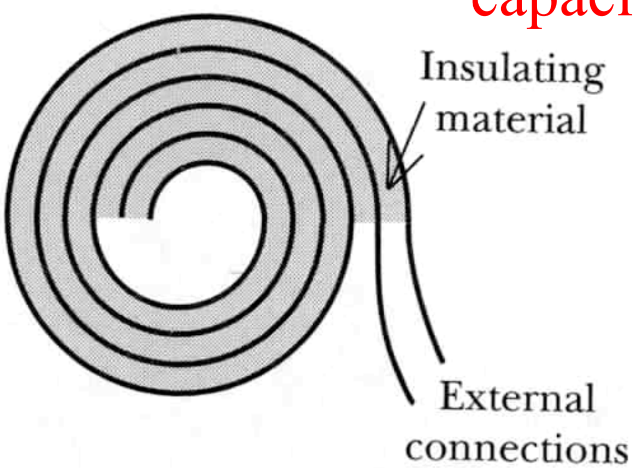
Capacitor: Construction and Symbols

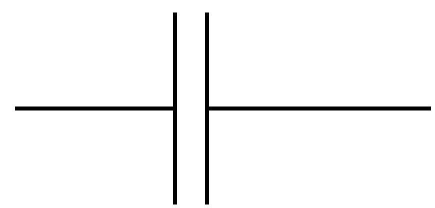


The capacitor in your set is similar to a large two-disk capacitor

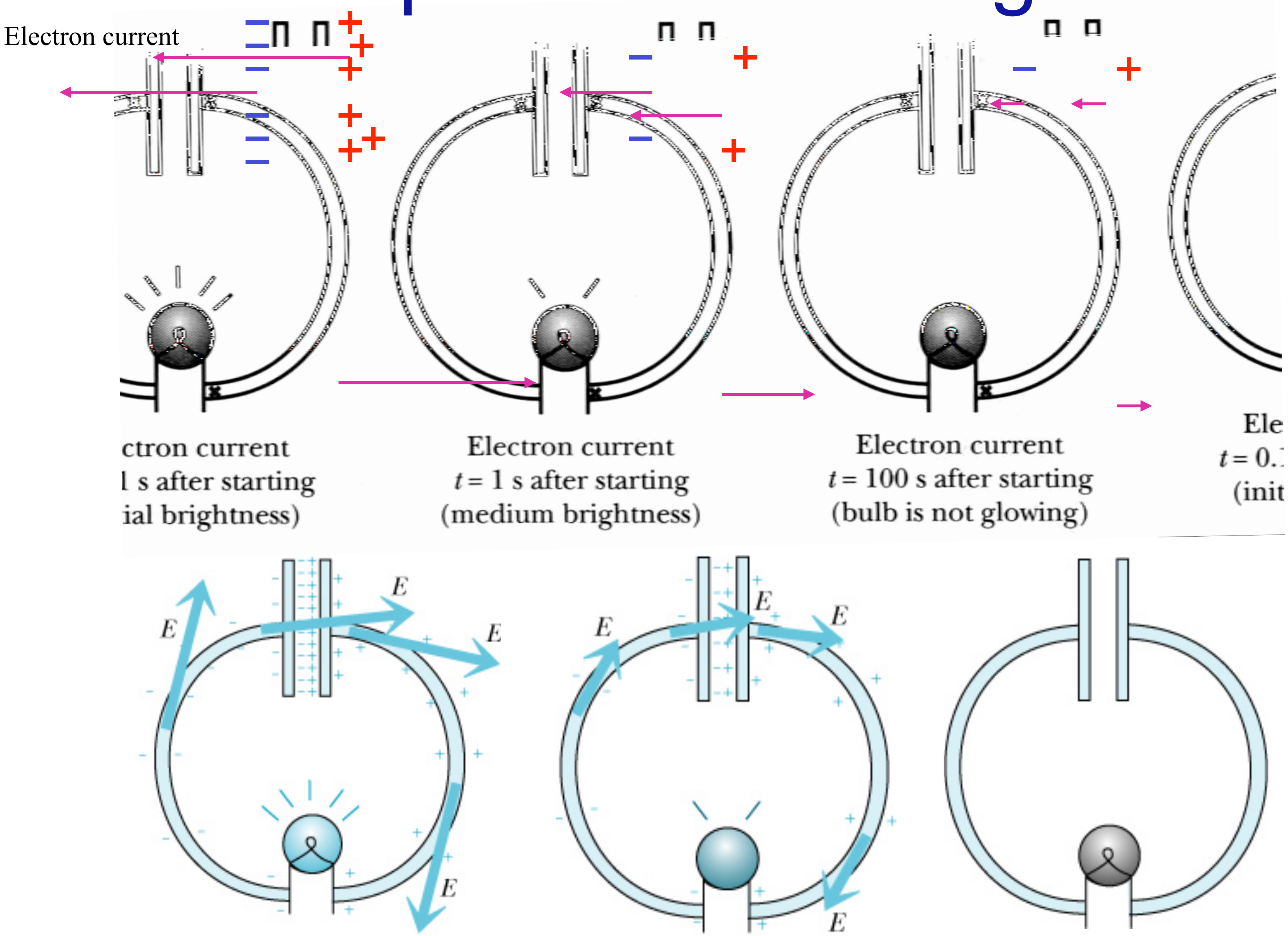


There is no connecting path through a capacitor





Capacitor: Discharge

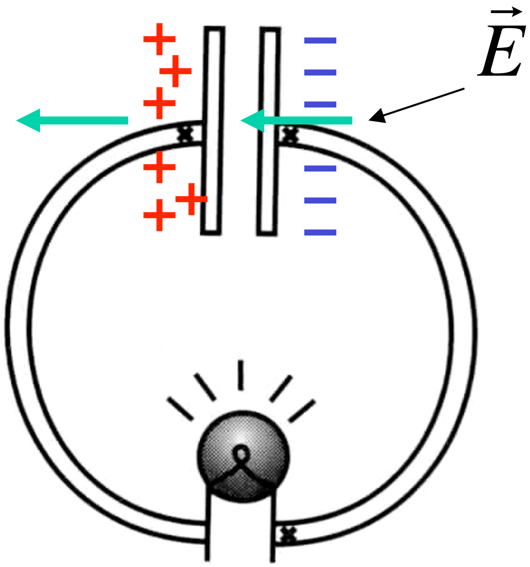


Capacitor Discharge

The fringe field of the capacitor plus the electric field of the charges on the surface of the wires drive current in a way to REDUCE the charge of the capacitor plates.

Recall that we derived an expression for the fringe field by considering the superposition of two charged disks separated by a distance s.

How is Discharging Possible?

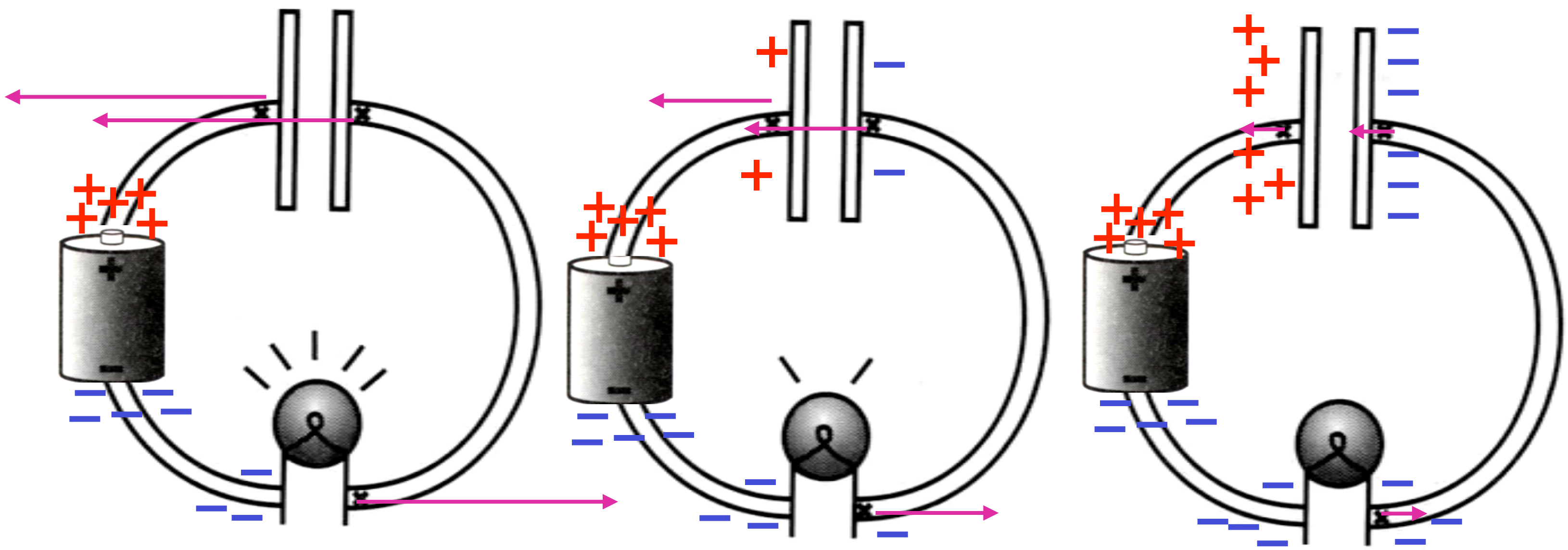


Positive and negative charges are attracted to each other: how can they leave the plates?

Fringe field is not zero!

Electrons in the wire near the negative plate feel a force that moves them away from the negative plate. Electrons near the positive plate are attracted towards it.

Capacitor: Charging



Electron current
$t = 0.1$ s after starting
(initial brightness)

Electron current
$t = 1$ s after starting
(medium brightness)

Electron current
$t = 100$ s after starting
(bulb is not glowing)

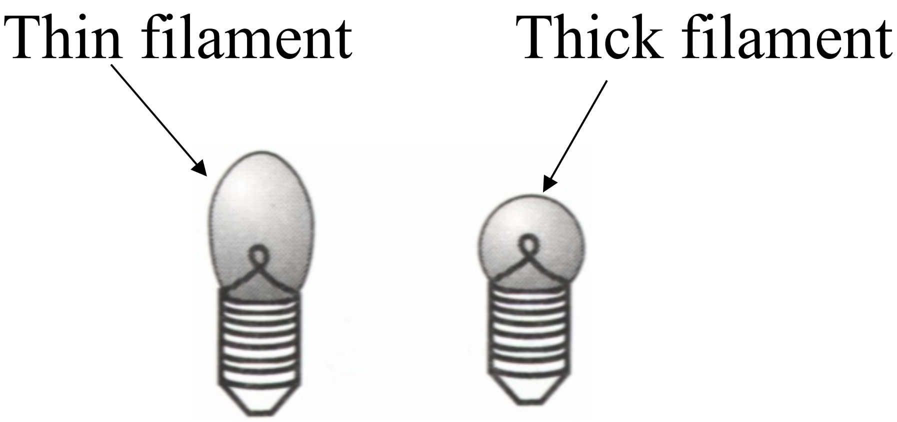
Fringe field of a capacitor rises until E=0 in a wire – static equilibrium. Fringe field opposes the flow of current!

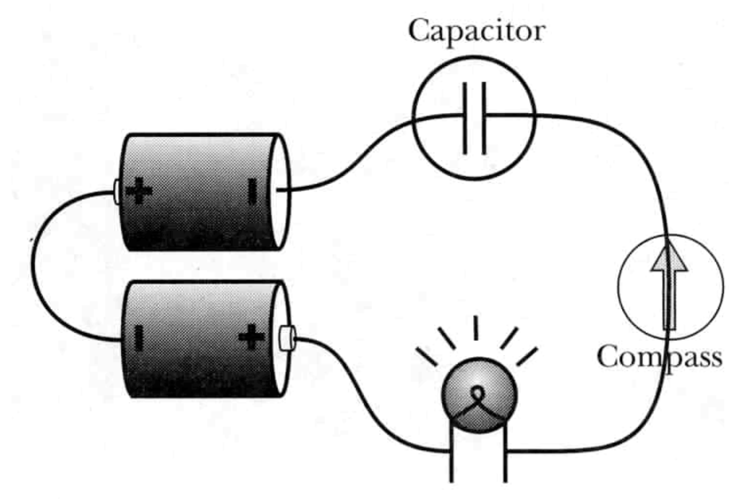
Capacitor: Charging

Why does current ultimately stop flowing in the circuit?

Ultimately, the fringe field of the capacitor and the field due to charges on the wire are such that E=0 inside the wire. At this point, i=0.

The Effect of Different Light Bulbs



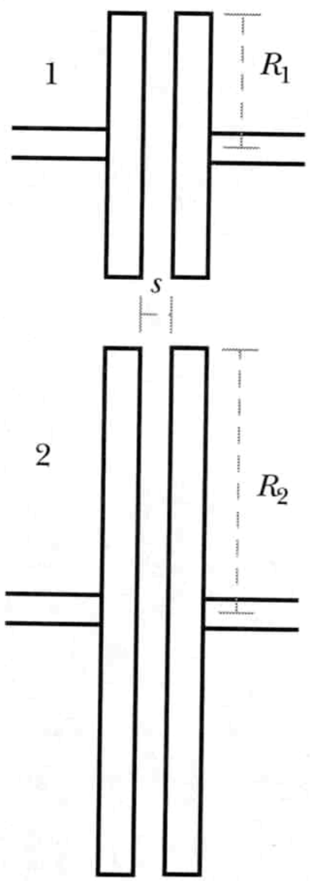


Which light bulb will glow longer?

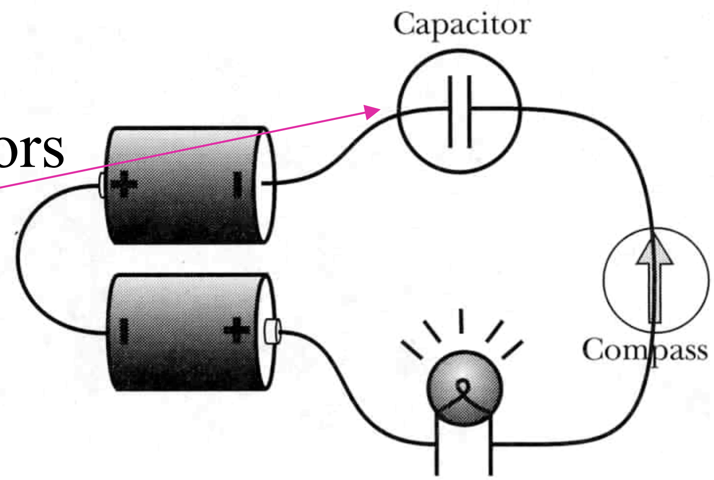
Why?

1) Round is brighter → capacitor gets charged more?
2) Long bulb glows longer → capacitor gets charged more?

Effect of the Capacitor Disk Size



Use two different capacitors in the same circuit

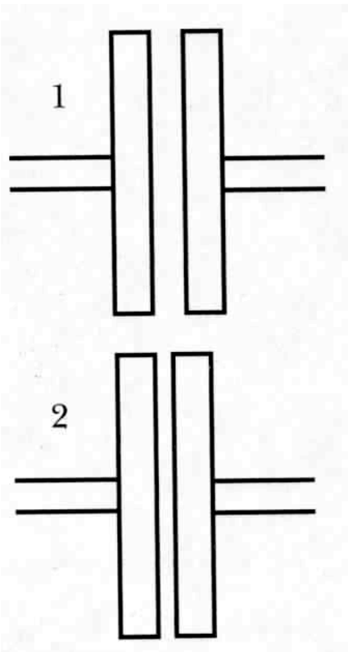


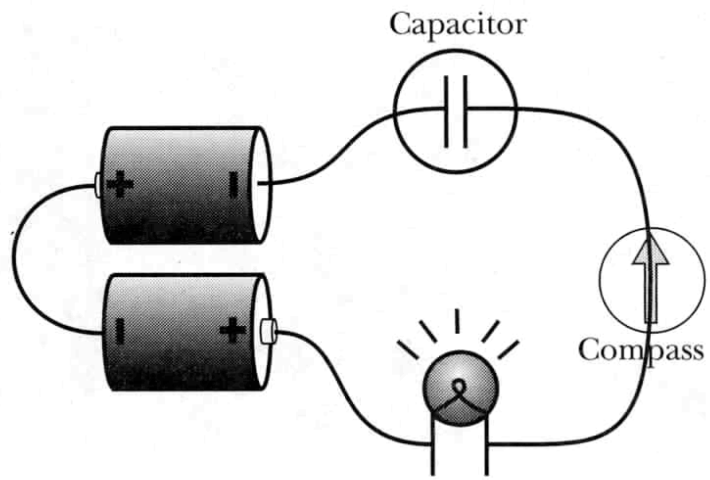
In the first moment, which capacitor will cause the bulb to produce more light?

Which capacitor will make the light bulb glow longer?

Fringe field: $E_1 \approx \frac{Q/A}{2\varepsilon_0}\frac{s}{R}$

Effect of the Capacitor Disk Separation



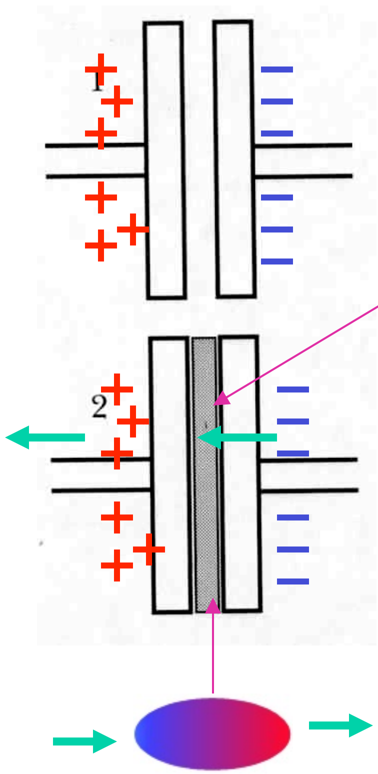


In the first moment, which capacitor will cause the bulb to produce more light?

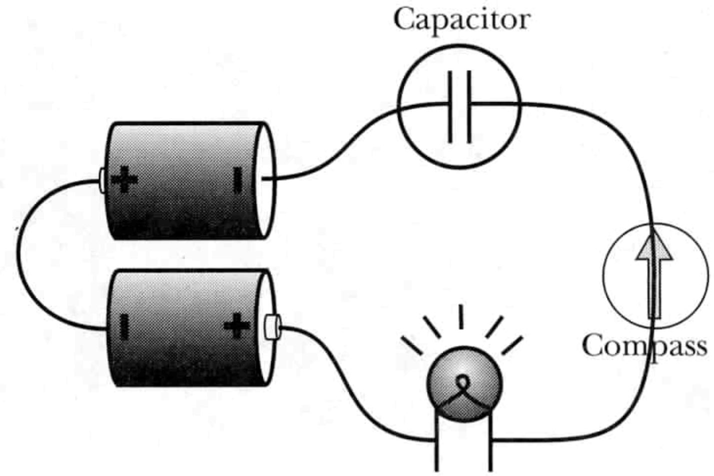
Which capacitor will make the light bulb glow longer?

Fringe field: $E_1 \approx \dfrac{Q/A}{2\varepsilon_0}\dfrac{s}{R}$

Effect of Insulator in Capacitor



Insulator



In the first moment, which capacitor will cause the bulb to produce more light?

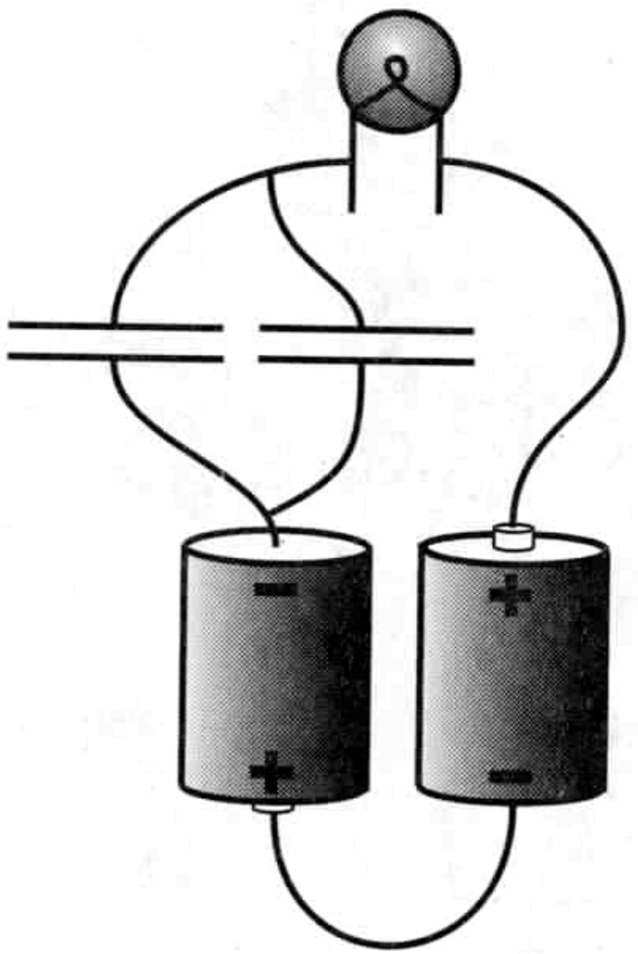
Which capacitor will make the light bulb glow longer?

Fringe field: $$E_1 \approx \frac{Q/A}{2\varepsilon_0}\frac{s}{R} - E_{dipoles}$$

The capacitors shown are initially uncharged. When connected to identical circuits, after 0.01 s of charging:

Consider two capacitors whose only difference is that capacitor number 1 has nothing between the plates, while capacitor number 2 has a layer of plastic in the gap. They are placed in two different circuits having similar batteries and bulbs in series with the Capacitor. In the first fraction of a second -

Parallel Capacitors



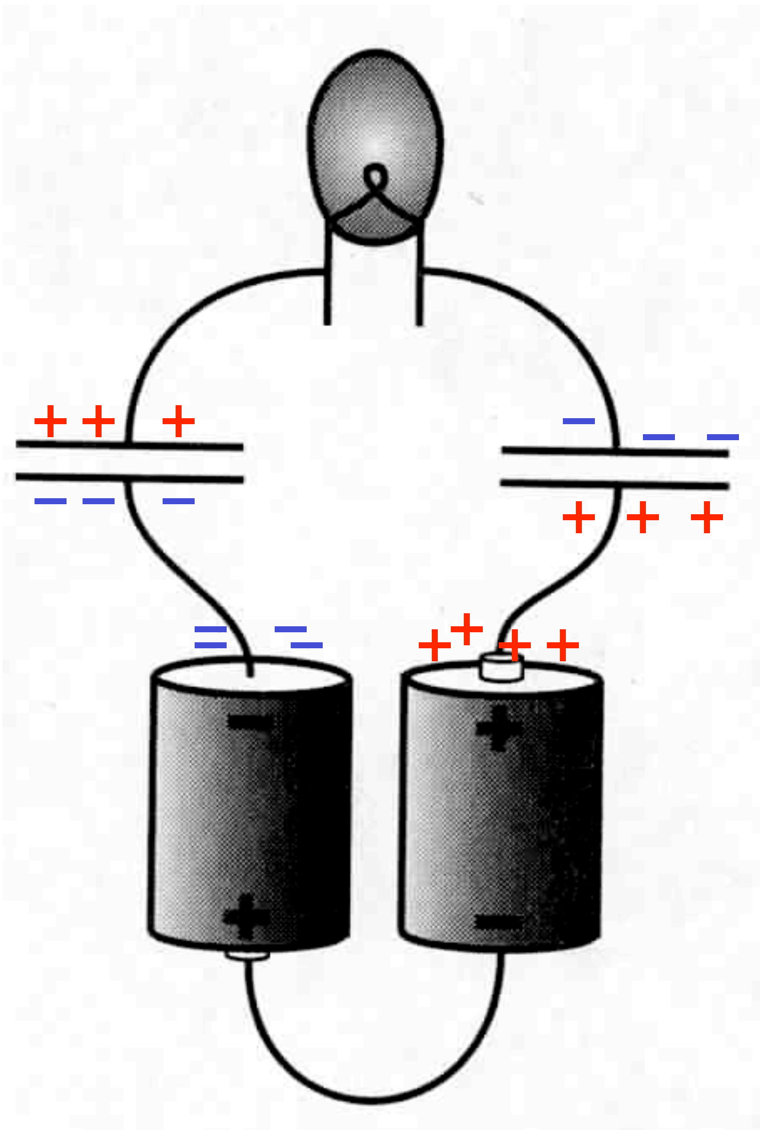
Initial moment: brighter?

Will it glow longer?

Fringe field: $E_1 \approx \dfrac{Q/A}{2\varepsilon_0}\dfrac{s}{R}$

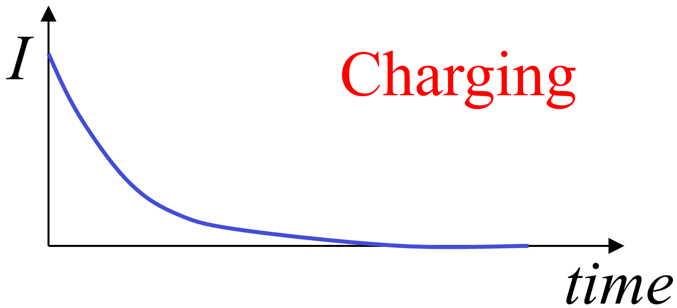
Capacitors in parallel effectively increase A

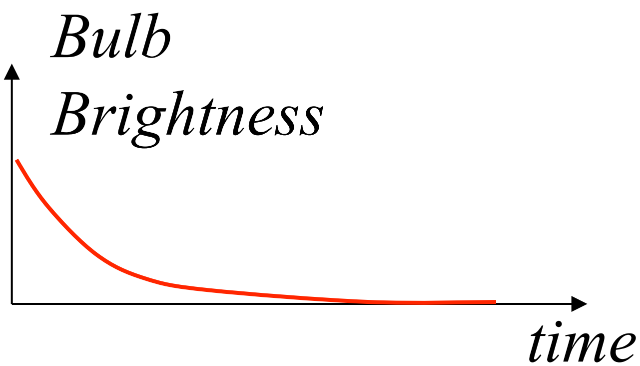
An Isolated Light Bulb

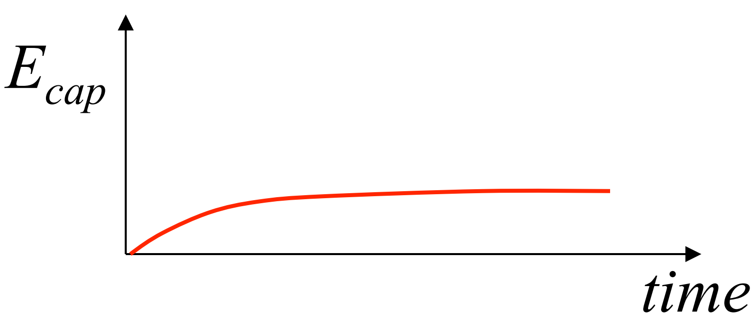


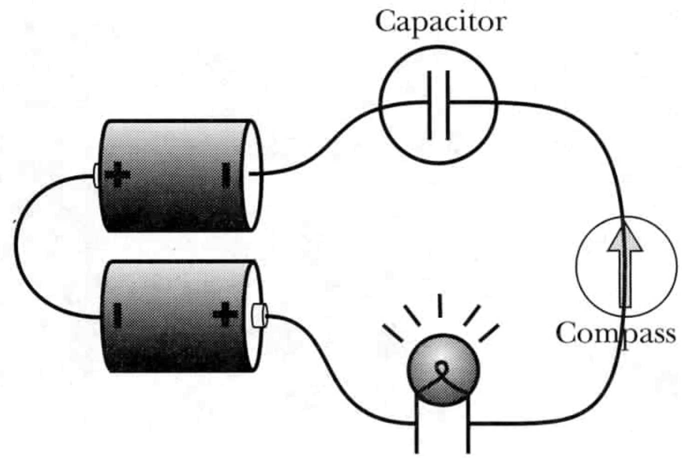
Will it glow at all?
How do electrons flow through the bulb?

Capacitor in a Circuit





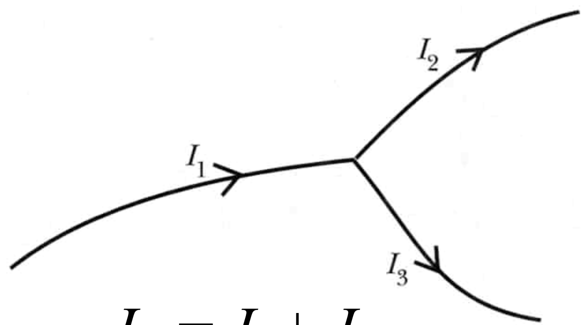




Energy conservation

Do 19.X.7!

The Current Node Rule in a Capacitor Circuit



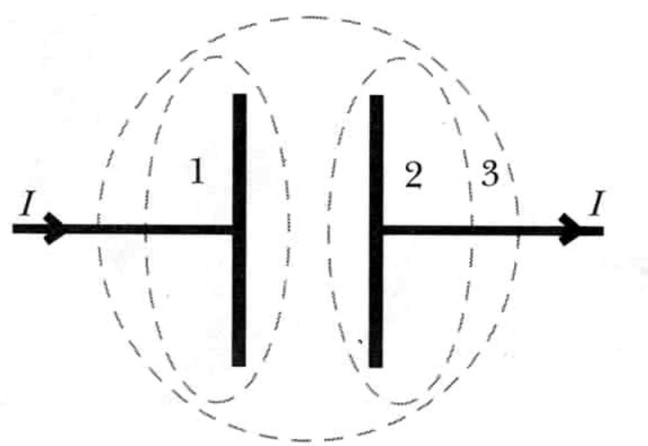
$$I_1 = I_2 + I_3$$

Charge conservation:

$$\sum_i I_i = 0$$

$I_i > 0$ for incoming
$I_i < 0$ for outgoing

…in steady state



Capacitor transients:
not a steady state!
Cannot use Kirchhoff rule for a part of a capacitor (area 1 or 2)

But can use for capacitor as a whole (area 3)

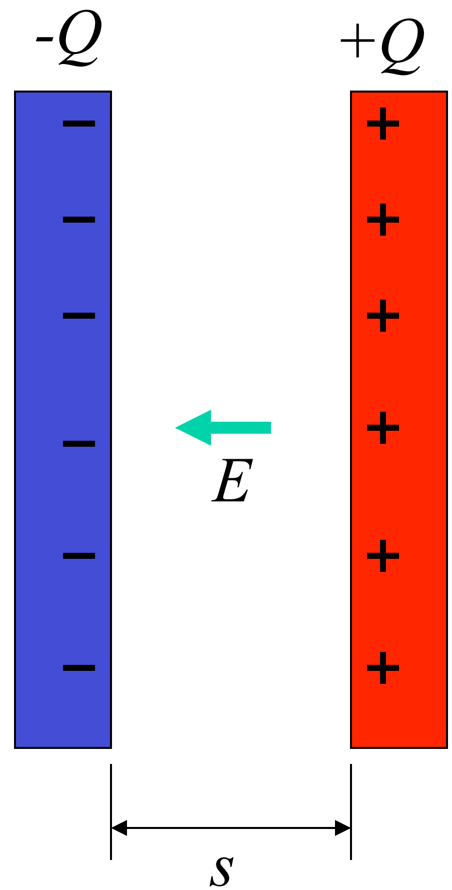
Capacitance

Electric field in a capacitor: $E = \dfrac{Q/A}{\varepsilon_0}$

$$\Delta V = -\int_i^f \vec{E} \bullet d\vec{l} \quad \longrightarrow \quad |\Delta V| = Es$$

$$|\Delta V| = \frac{Q/A}{\varepsilon_0} s \quad \longrightarrow \quad Q = \frac{\varepsilon_0 A}{s} |\Delta V|$$

In general: $Q \sim |\Delta V|$



Definition of capacitance:

$$Q = C|\Delta V|$$

Capacitance

Capacitance of a parallel-plate capacitor:

$$\boxed{C = \frac{\varepsilon_0 A}{s}}$$

Exercise

A capacitor is formed by two rectangular plates 50 cm by 30 cm, and the gap between the plates is 0.25 mm. What is its capacitance?

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

$$C = \frac{\varepsilon_0 A}{s} = \frac{\left(9 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}\right)\left(0.15\ \mathrm{m^2}\right)}{2.5 \times 10^{-4}\ \mathrm{m}} = 5.4 \times 10^{-9}\ \mathrm{F} = 5.4\ \mathrm{nF}$$

A Capacitor With an Insulator Between the Plates

No insulator:

$$\boxed{E = \frac{Q/A}{\varepsilon_0}}$$

$$|\Delta V| = Es$$

$$|\Delta V| = \frac{Q/A}{\varepsilon_0}s$$

$$Q = \frac{\varepsilon_0 A}{s}|\Delta V|$$

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

With insulator:

$$\boxed{E = \frac{Q/A}{K\varepsilon_0}}$$

$$|\Delta V| = Es$$

$$|\Delta V| = \frac{Q/A}{K\varepsilon_0}s$$

$$Q = \frac{K\varepsilon_0 A}{s}|\Delta V|$$

$$C = K\frac{\varepsilon_0 A}{s}$$