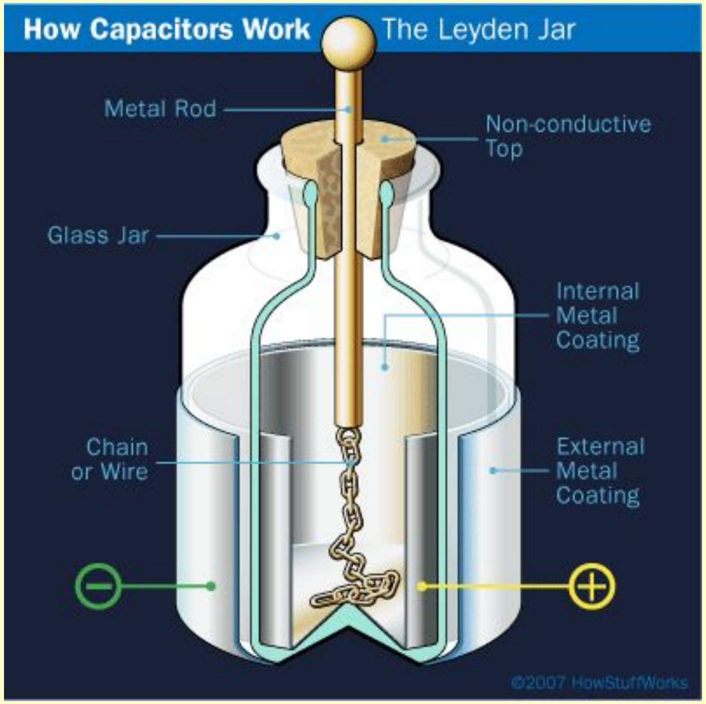
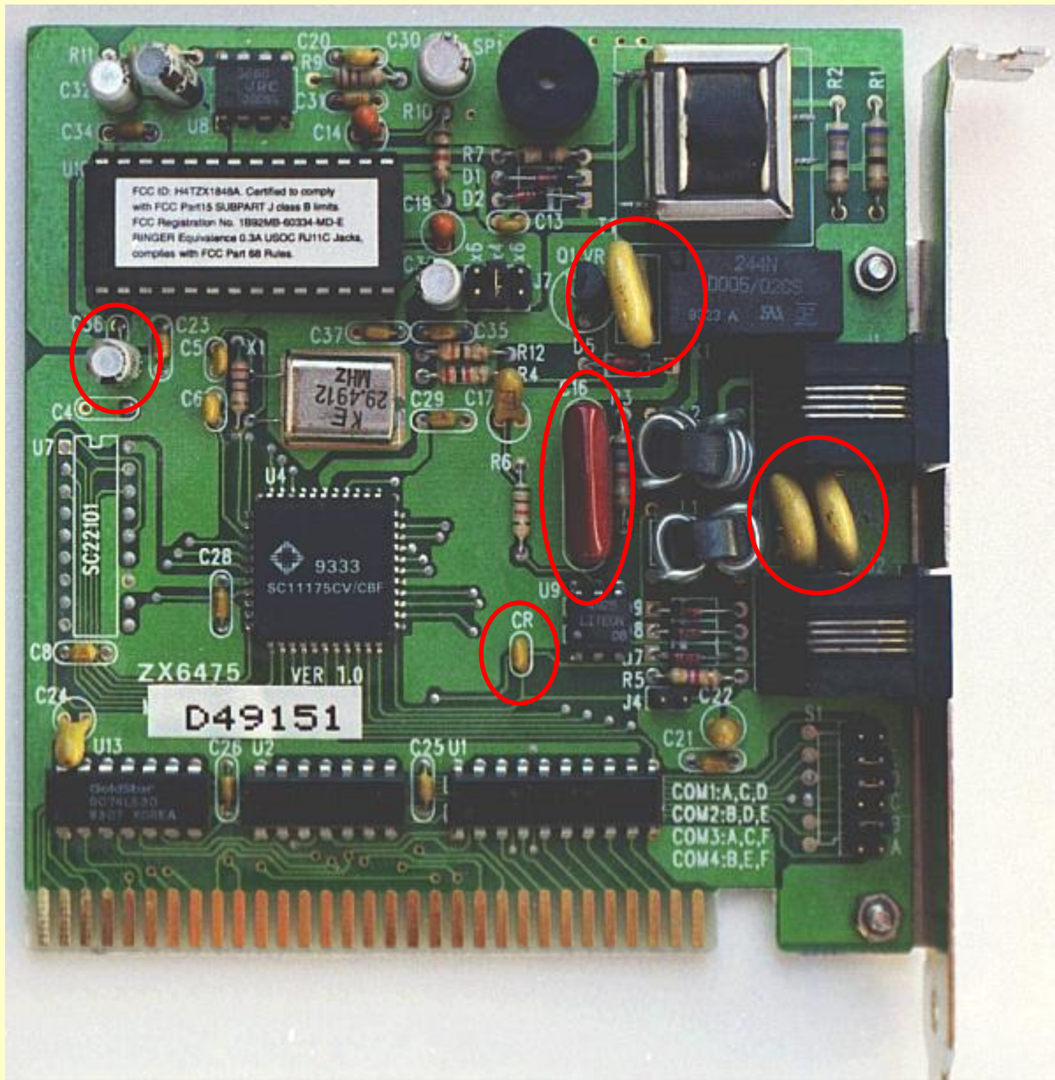
Capacitors

- A capacitor is a device for storing charge and electrical potential energy.

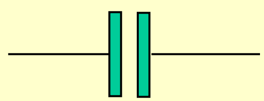


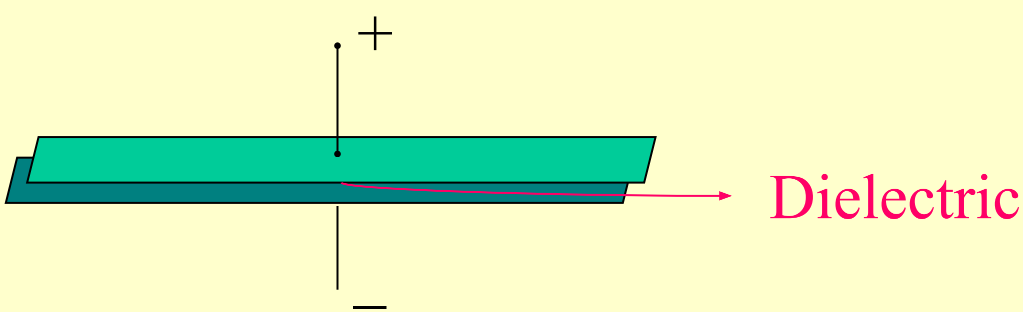
Capacitors in an electronic circuit

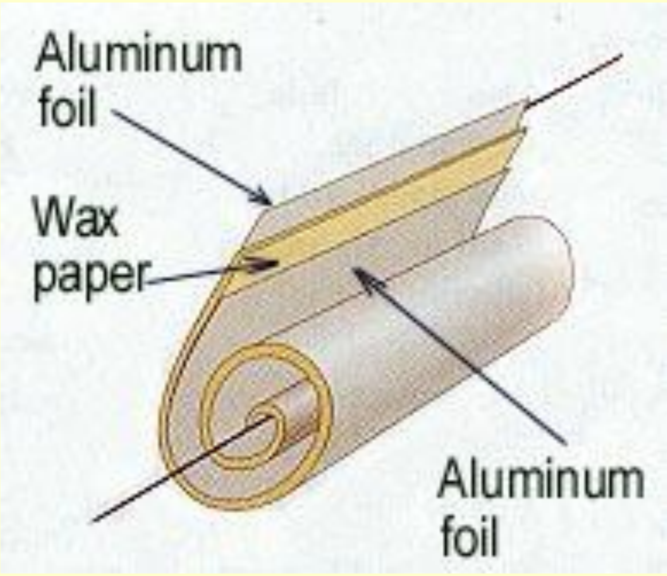


Capacitors

- All capacitors consists of two metal plates separated by an insulator. The insulator is called dielectric. (e.g. polystyrene, oil or air)
- Circuit symbol:

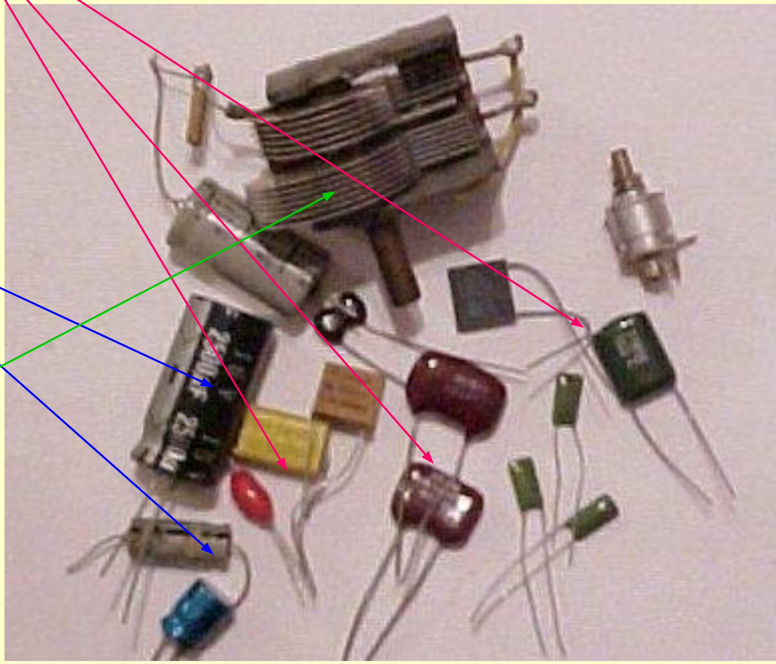






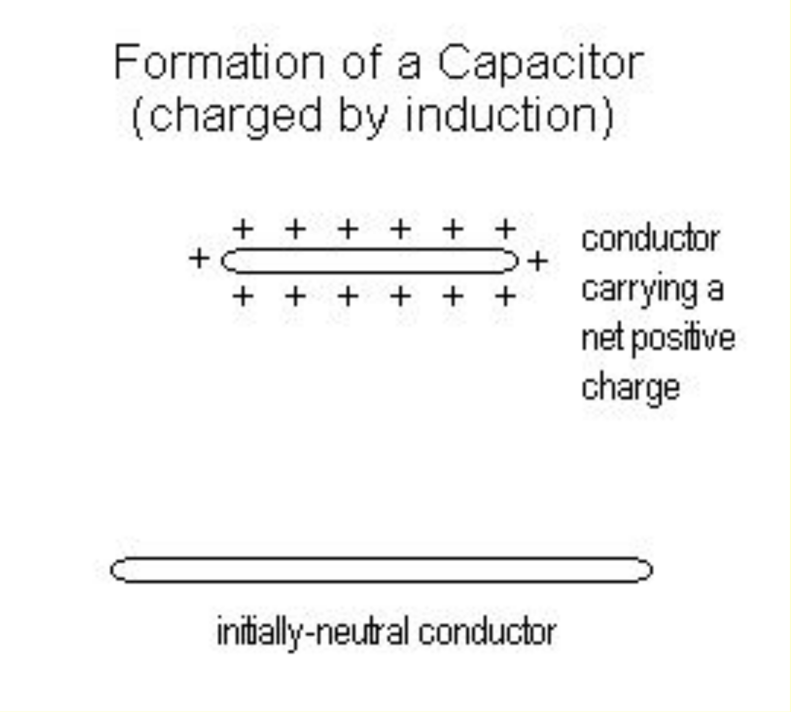
Examples of Capacitors

- Paper, plastic, ceramic and mica capacitors
  - Non-polarized types can be connected either way round.
- Electrolytic capacitors
  - Polarized types must be connected so that there is d.c. through them in the correct direction.
- Air capacitors
  - The capacitance is changed by varying the interleaved area.



Formation of a Capacitor

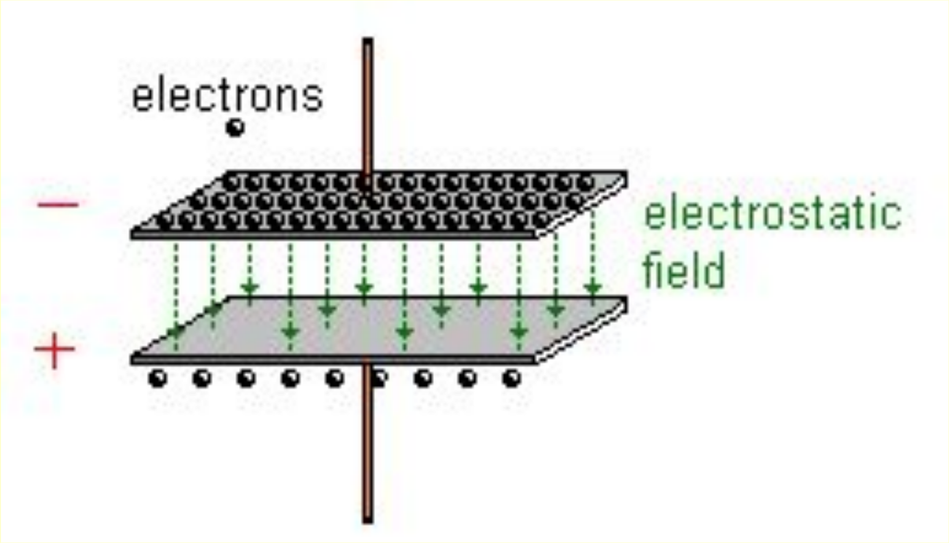
- Capacitors are formed all of the time in everyday situations:
  - when a charged thunderstorm cloud induces an opposite charge in the ground below,
  - when you put your hand near the monitor screen of this computer.



http://micro.magnet.fsu.edu/electromag/java/lightning/index.html

Charged Capacitor

- A capacitor is said to be **charged** when there are more electrons on one conductor plate than on the other.

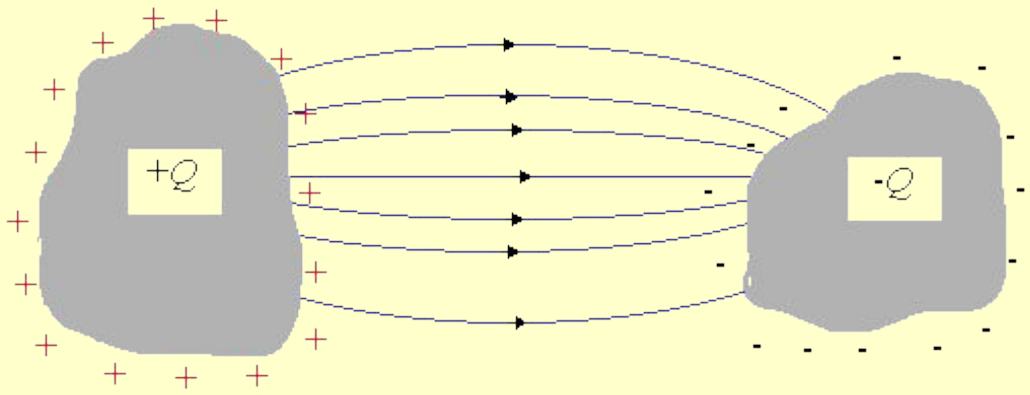


When a capacitor is charged, energy is stored in the **dielectric material** in the form of an **electrostatic field**.

http://micro.magnet.fsu.edu/electromag/java/capacitor/index.html

Capacitance (1)

- Consider any isolated pair of conductors with charge Q



Capacitance is defined as $$C = \frac{Q}{V}$$ Unit : farad (F)

Where Q = charge on one conductor
V = potential difference between two conductors

Capacitance (2)

- The capacitance of a conductor is the charge required to cause unit change in the potential of the conductor.
- A one-farad capacitor stores one coulomb of charge when a potential of 1 volt is applied across the terminals of the capacitor.
- The smaller the change in potential of the conductor when a certain charge is transferred to it, the more charge it can store before breakdown occurs.
- In electronics, the microfarad (μF) and the picofarad (pF) are usually used to measure capacitance.

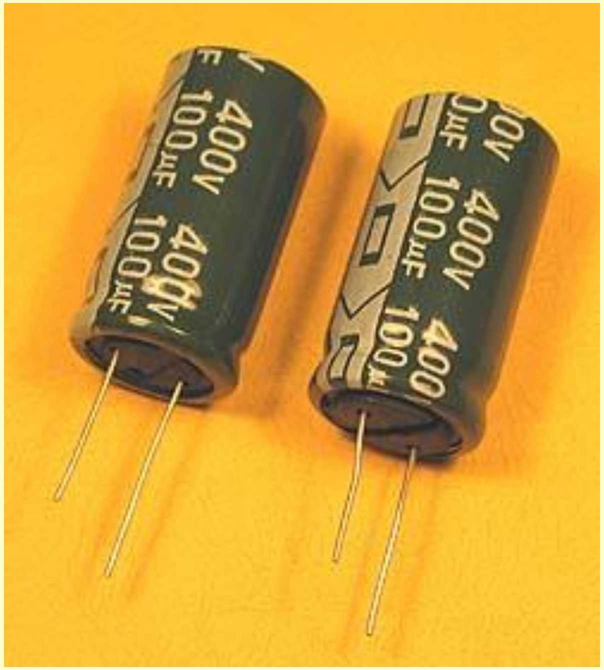
Capacitance of a Capacitor

$$C = \frac{Q}{V}$$

- Note that Q is not the net charge on the capacitor, which is zero.
- Capacitance is a measure of a capacitor's ability to store charge.
- The more charge a capacitor can hold at a given potential difference, the larger is the capacitance.
- Capacitance is also a measure of the energy storage capability of a capacitor.

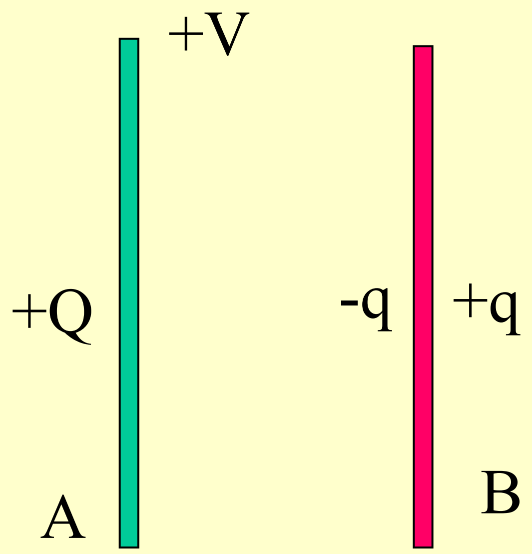
Voltage Rating of Capacitors

- If the voltage applied across the capacitor is too great, the dielectric will break down and arcing will occur between the capacitor plates.
- The voltage rating of the capacitor is the maximum voltage that can be steadily applied without danger of breaking down the dielectric.



Capacitance of Metal Plates

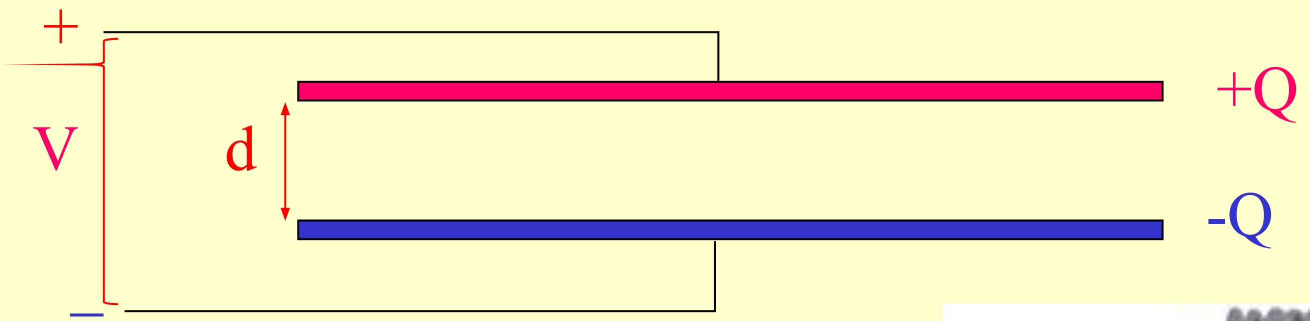
- Consider a metal plate A which has a charge +Q as shown.
- If the plate is isolated, A will then have some potential V relative to earth and its capacitance C = Q/V.



- Now suppose that another metal B is brought near to A.
- Induced charges –q and +q are then obtained on B. This lowers the potential V to a value V′.
- So C′ = Q/V′ > C.

Parallel Plate Capacitor

- Suppose two parallel plates of a capacitor each have a charge numerically equal to Q.



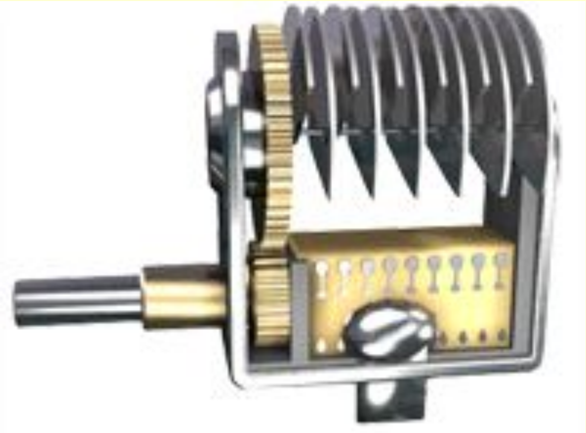
- As $C = Q/V$

  Where $Q = \sigma A = \varepsilon_o E A$

  and

  $V = Ed$

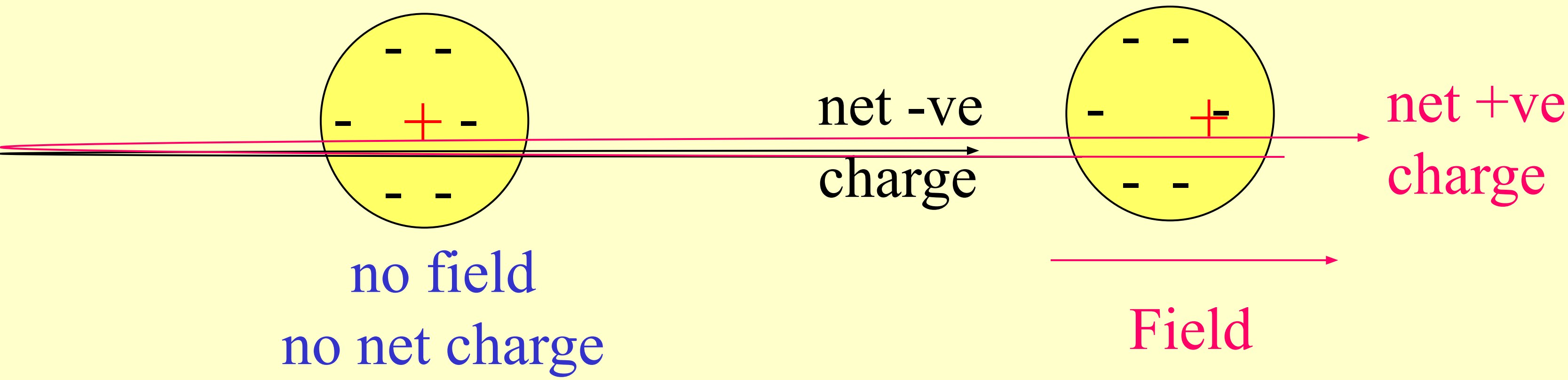
  $\therefore\ C = \varepsilon_o A/d$



- C depends on the geometry of the conductors.

Action of Dielectric (1)

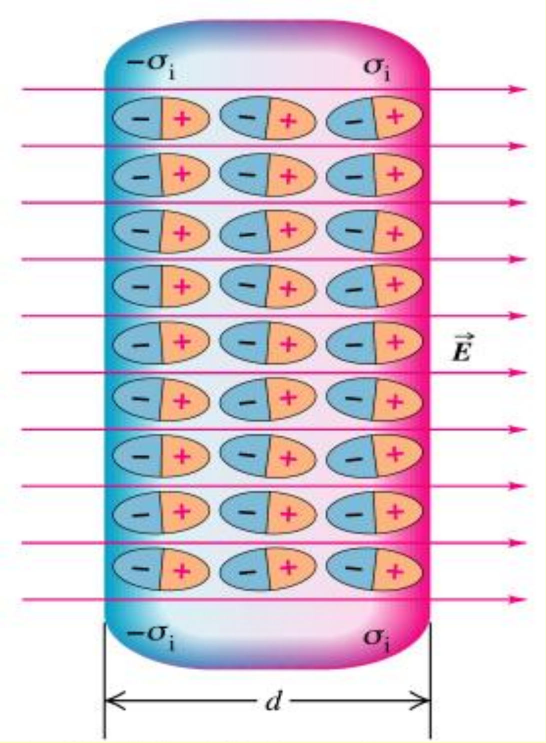
- A molecule can be regarded as a collection of atomic nuclei, positively charged, and surrounded by a cloud of negative electrons.



- When the molecule is in an electric field, the nuclei are urged in the direction of the field, and the electrons in the opposite direction.
- The molecule is said to be polarized.

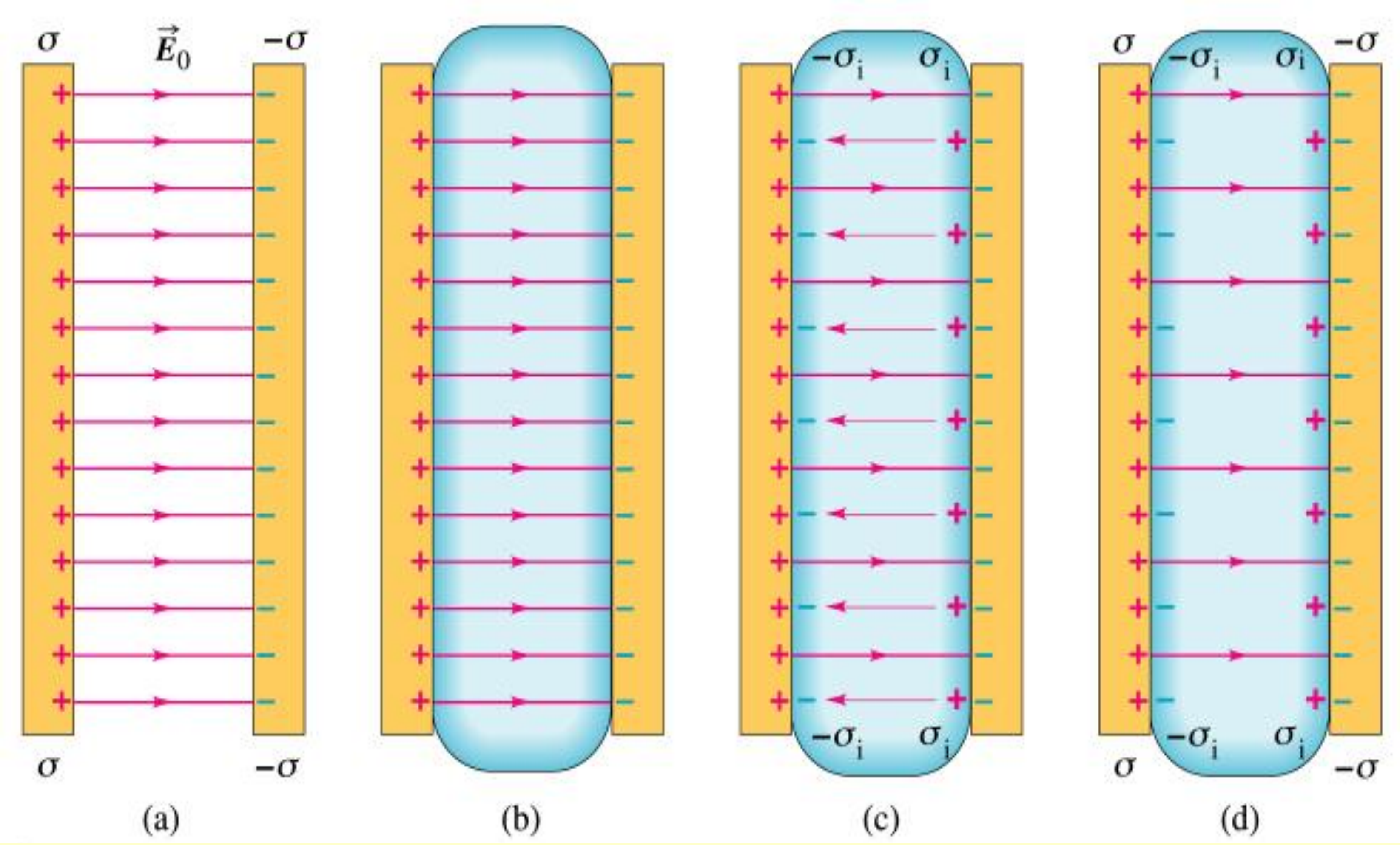
Action of Dielectric (2)

- When a dielectric is in a charged capacitor, charges appear as shown below.
- These charges are of opposite sign to the charges on the plates.



- The charges reduce the electric field strength E between the plates.
- The potential difference between the plates is also reduced as $E = V/d$.
- From $C = Q/V$, it follows that C is increased.

Action of Dielectric (3)



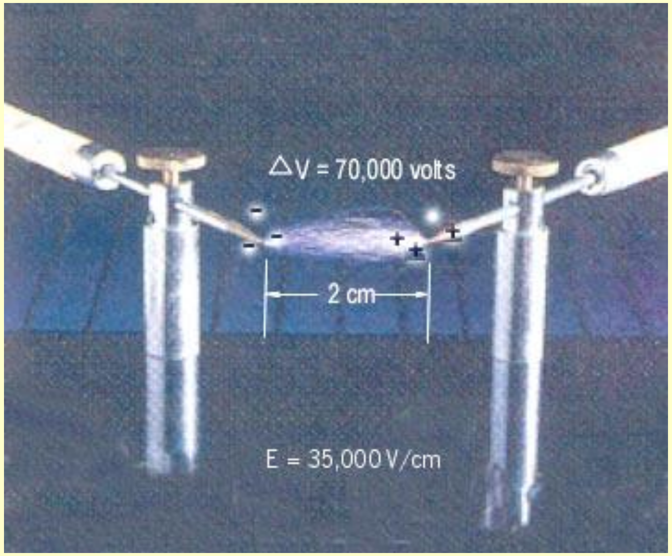
Functions of Dielectrics

- It solves the mechanical problem of maintaining two large metal plates at a very small separation without actual contact.
- Using a dielectric increases the maximum possible potential difference between the capacitor plates without allowing discharge.
- With the dielectric present, the p.d. for a given charge Q is reduced by a factor ε_r and hence the capacitance of the capacitor is increased.

Relative permittivity and Dielectric Strength

- The ratio of the capacitance with and without the dielectric between the plates is called the *relative permittivity*. or *dielectric constant*.

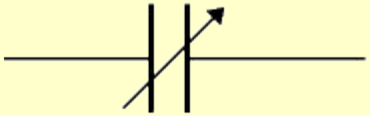
$$\varepsilon_r = \frac{C_d}{C_v} = \frac{\varepsilon}{\varepsilon_o}$$



- The strength of a dielectric is the potential gradient (electric field strength) at which its insulation breakdown.

Relative permittivity of some dielectrics

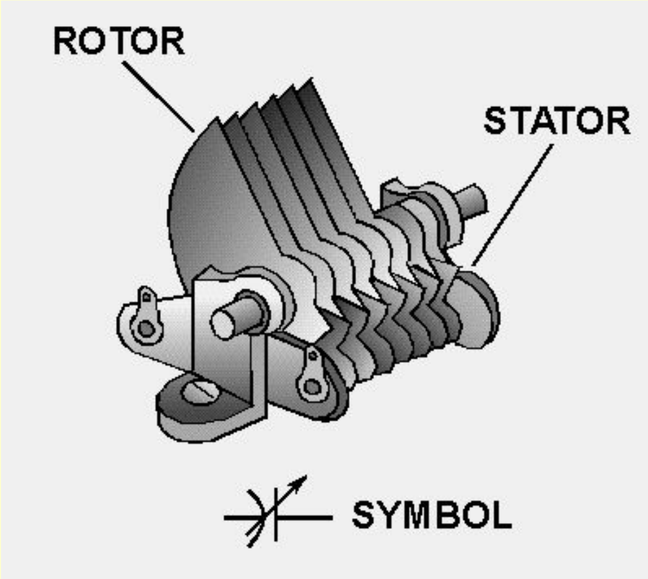
Dielectric	Relative permittivity
Vacuum	1
Air	1.0006
Polythene	2.3
Waxed paper	2.7
Mica	5.4
Glycerin	43
Pure water	80
Strontium titanate	310



Variable Capacitor

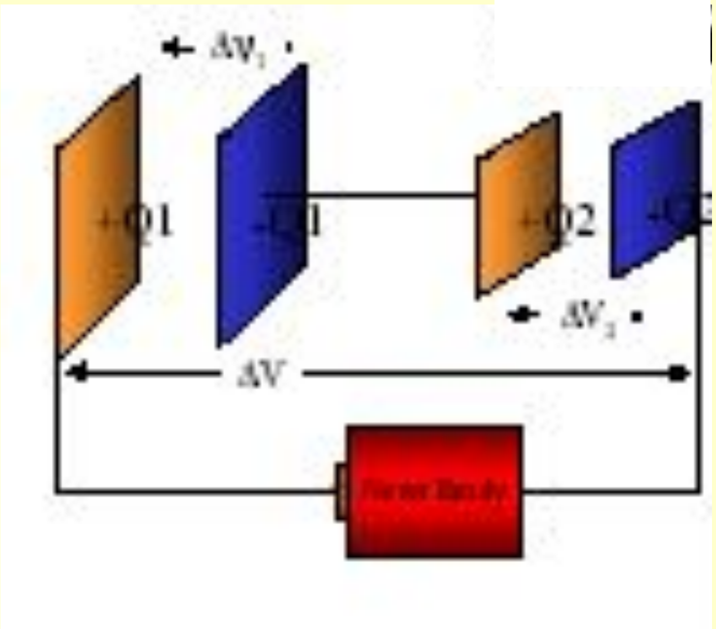
http://micro.magnet.fsu.edu/electromag/java/varcapacitor/index.html

- A typical variable capacitor consists of two sets of plates.
  - One set is called the rotor and the other the stator. The rotor is connected to the adjustment knob outside the capacitor.
- The two sets of plates are close together but not touching.
  - Air is the dielectric in a variable capacitor.
- As the capacitor is adjusted, the sets of plates become more or less meshed, increasing or decreasing the area of overlap between the plates.
  - As the plates become more meshed, capacitance increases.
  - As the plates become less meshed, capacitance decreases.



Combination of Capacitor (1)

- In series



$$Q = Q_1 = Q_2 = Q_3$$

$$V = V_1 + V_2 + V_3$$

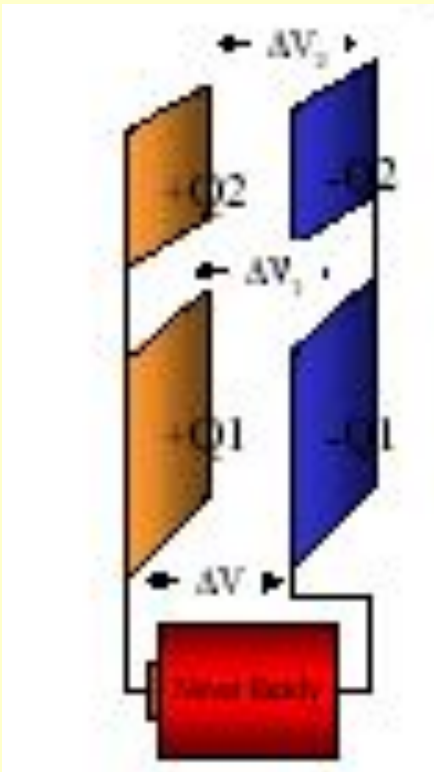
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$V_1 : V_2 : V_3 = \frac{1}{C_1} : \frac{1}{C_2} : \frac{1}{C_3}$$

The resultant capacitance is smaller than the smallest Individual one.

Combination of Capacitors (2)

- In parallel



$$Q = Q_1 + Q_2 + Q_3$$

$$V = V_1 = V_2 = V_3$$

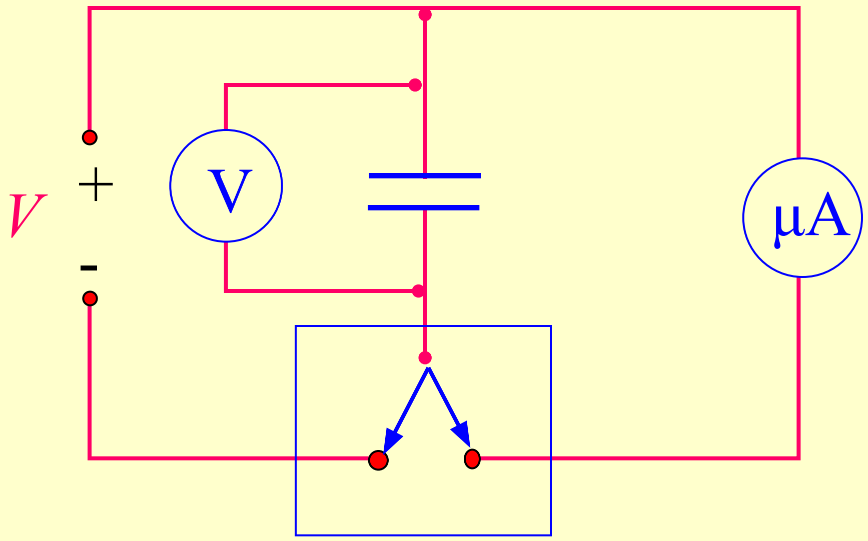
$$C = C_1 + C_2 + C_3$$

$$Q_1 : Q_2 : Q_3 = C_1 : C_2 : C_3$$

The resultant capacitance is greater
Than the greatest individual one.

Measurement of Capacitance using Reed Switch

- The capacitor is charged at a frequency *f* to the p.d *V* across the supply, and each time discharged through the microammeter.



During each time interval 1/*f*, a charge *Q* = *CV* is passed through the ammeter.

$$\therefore I = \frac{Q}{1/f} = fCV$$

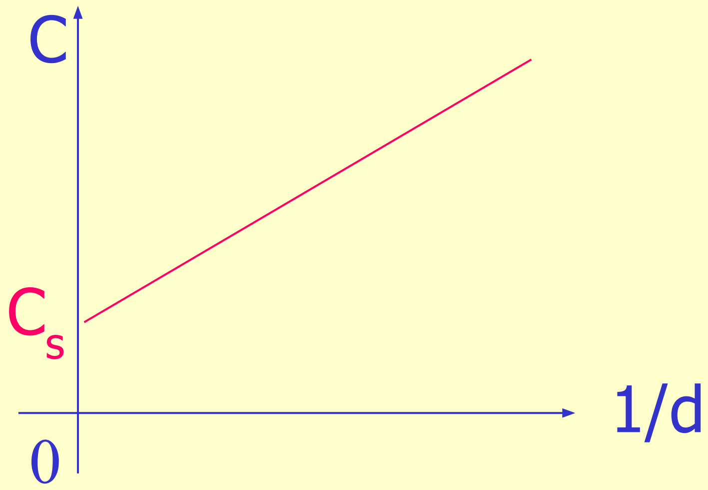
Measurement of Capacitance using Electrometer

Stray Capacitance

- The increased capacitance due to nearby objects is called the stray capacitance C_s which is defined by
- $C = C_o + C_s$
  - Where C is the measured capacitance.
- Stray capacitance exists in all circuits to some extent. While usually to ground, it can occur between any two points with different potentials.
- Sometimes stray capacitance can be used to advantage, usually you take it into account but often it's a monumental pain.

Measurement of Stray Capacitance

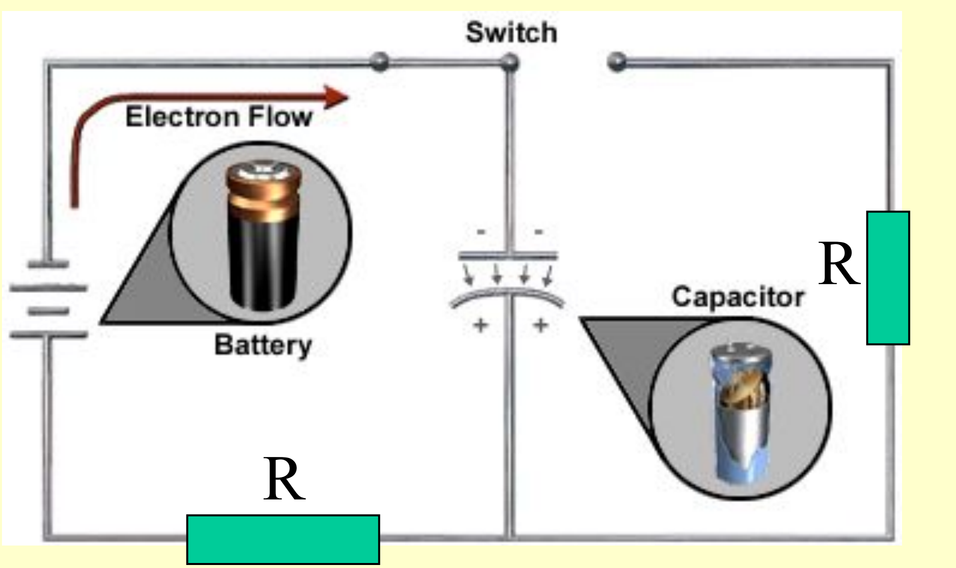
- In measuring capacitance of a capacitor, the stray capacitance can be found as follows:

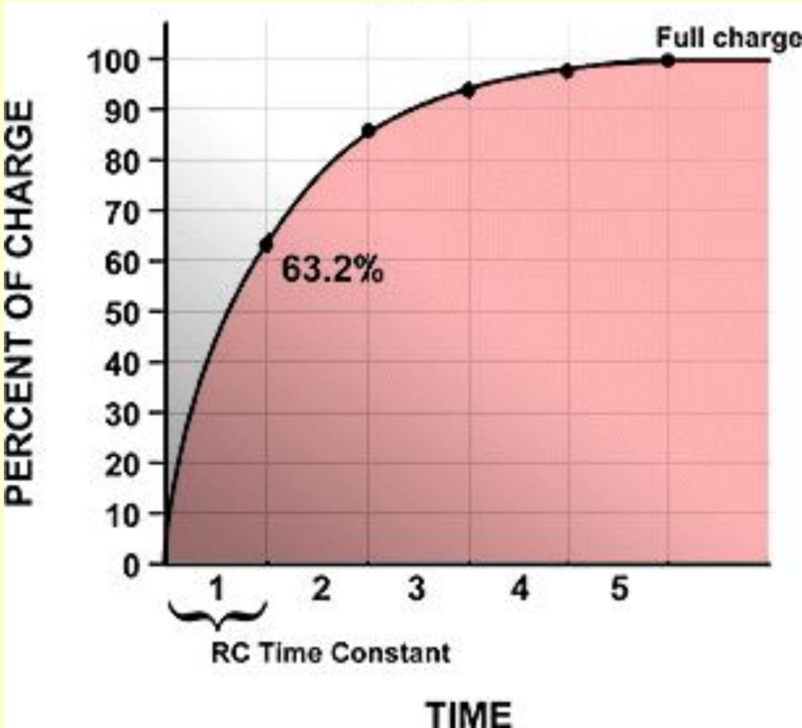


$$C = \frac{\varepsilon_o A}{d} + C_s$$

Charging of Capacitors (1)

- As a capacitor becomes charged, the current flow decreases because the voltage developed by the capacitor increases over time and opposes the source voltage.

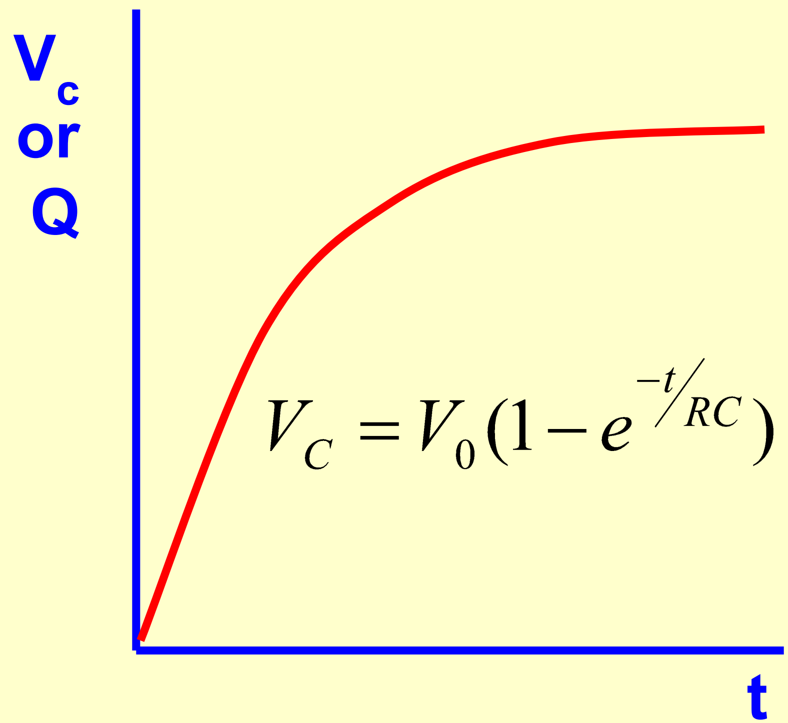




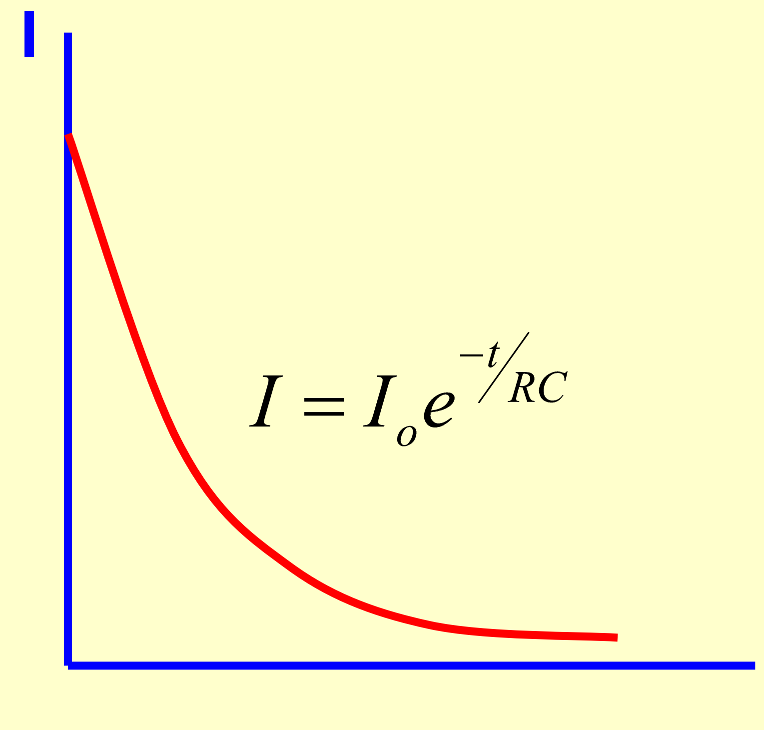
http://www.microscopy.fsu.edu/electromag/java/capacitor/index.html

Charging a Capacitor (2)

- Voltage-charge characteristics

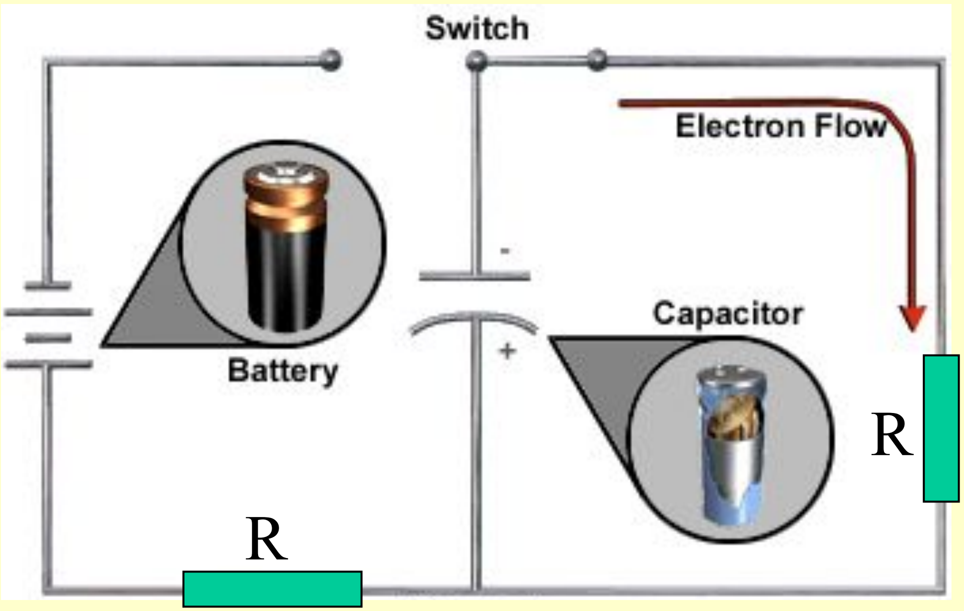


- Current flow



http://lectureonline.cl.msu.edu/~mmp/kap23/RC/app.htm

Discharging of Capacitors (1)

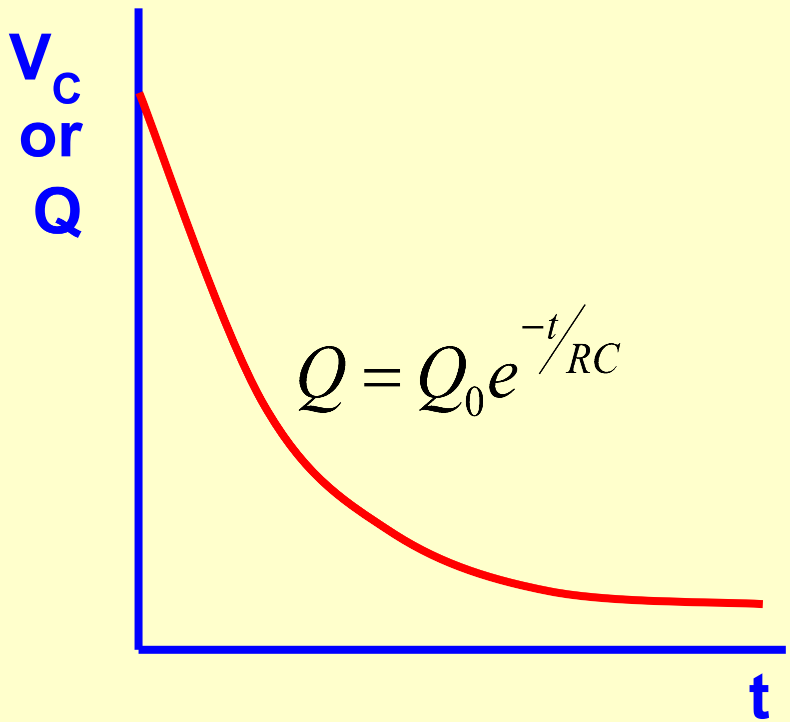


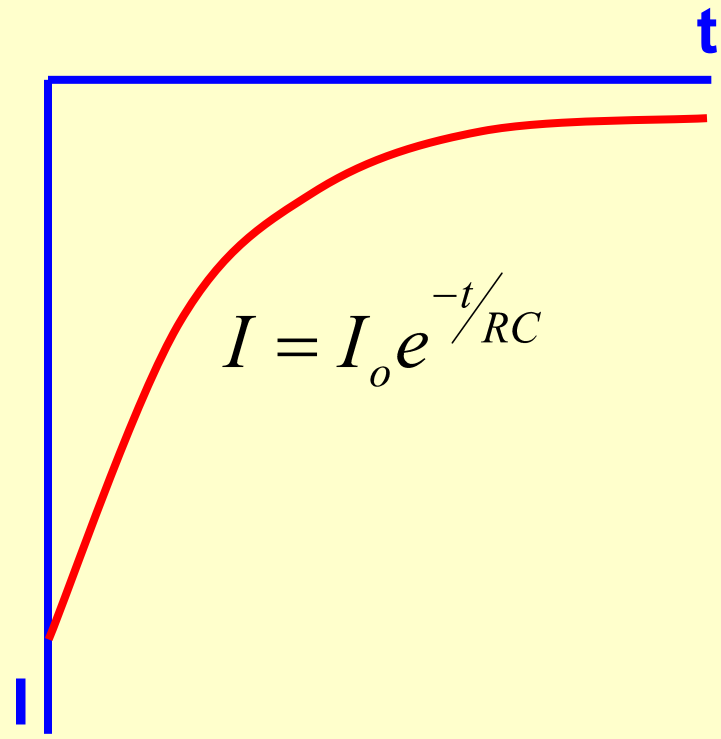
- The charged capacitor is the source of voltage for the current flow. The current will cease flowing when the charges of the two plates are again equal, meaning that the capacitor is completely discharged.

http://www.phy.ntnu.edu.tw/java/rc/rc.html

Discharging a Capacitor (2)

- Voltage-charge characteristics
- Current flow



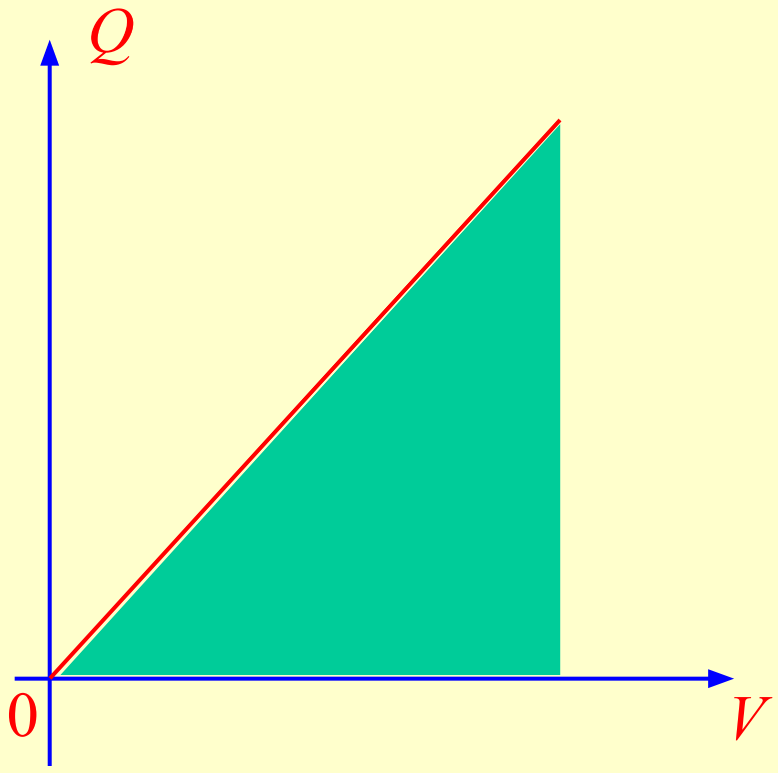


Time Constant (τ)

- $\tau = CR$
- The time constant is used to measure how long it takes to charge a capacitor through a resistor.
- The time constant may also be defined as the time taken for the charge to decay to 1/e times its initial value.
- The greater the value of *CR*, the more slowly the charge is stored.
- Half-life
  - The half-life is the time taken for the charge in a capacitor to decay to half of its initial value.
  - $T_{1/2} = CR \ln 2$

Energy Stored in a Charged Capacitor

http://www.matter.org.uk/schools/Content/Capacitors/energy2.html



- The area under the graph gives the energy stored in the capacitor.

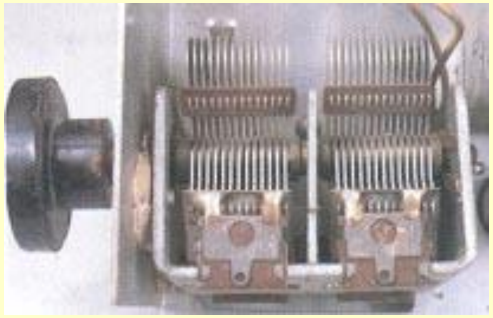
$$E = \frac{1}{2}QV$$

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

$$= \frac{1}{2}\frac{Q^2}{C}$$

Applications of Capacitors (1)

- The capacitance is varied by altering the overlap between a fixed set of metal plates and a moving set. These are used to tune radio receiver.

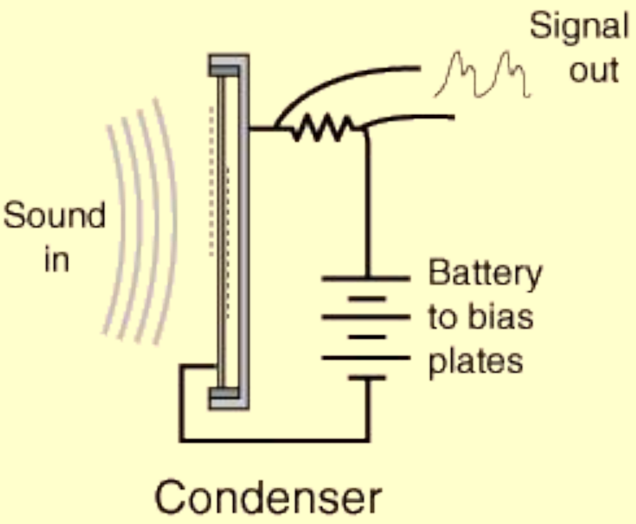


http://www.microscopy.fsu.edu/electromag/java/radio/index.html

- Press the key on a computer keyboard reduce the capacitor spacing thus increasing the capacitance which can be detected electronically.

Applications of Capacitors (2)

- Condenser microphone
  - sound pressure changes the spacing between a thin metallic membrane and the stationary back plate. The plates are charged to a total charge Q=CV.



– A change in plate spacing will cause a change in charge Q and force a current through resistance R. This current "images" the sound pressure, making this a "pressure" microphone.

http://www.microscopy.fsu.edu/electromag/java/microphone/index.html

Applications of Capacitors (3)

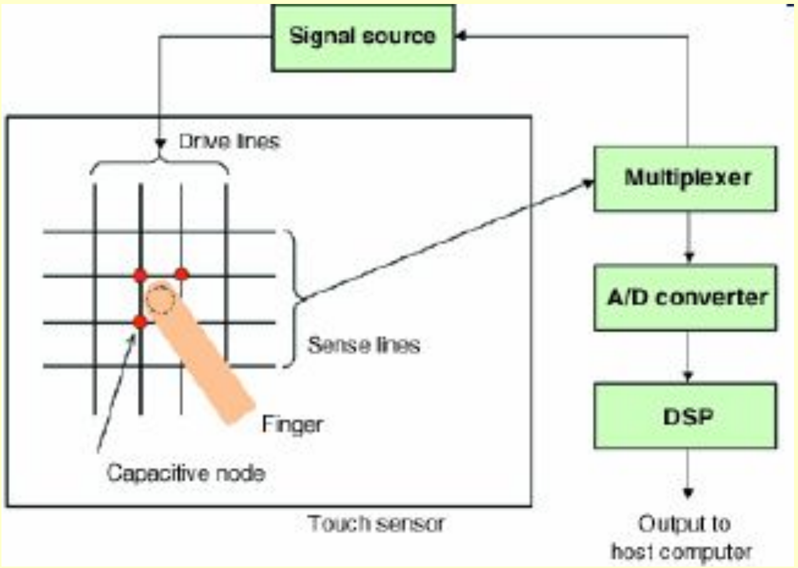
- Electronic flash on a camera
  - The battery charges up the flash's capacitor over several seconds, and then the capacitor dumps the full charge into the flash tube almost instantly.
  - A high voltage pulse is generated across the flash tube.
  - The capacitor discharges through gas in the the flash tube and bright light is emitted.

http://electronics.howstuffworks.com/capacitor.htm

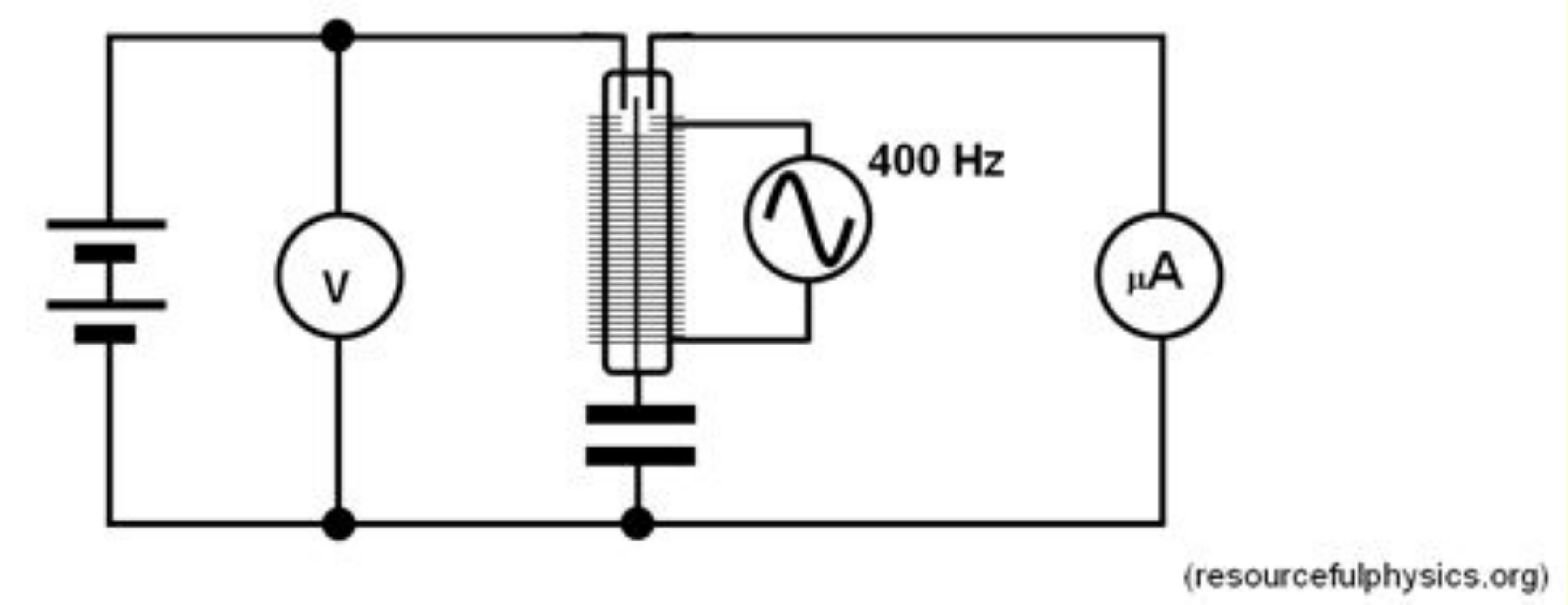
Applications of Capacitors (4)

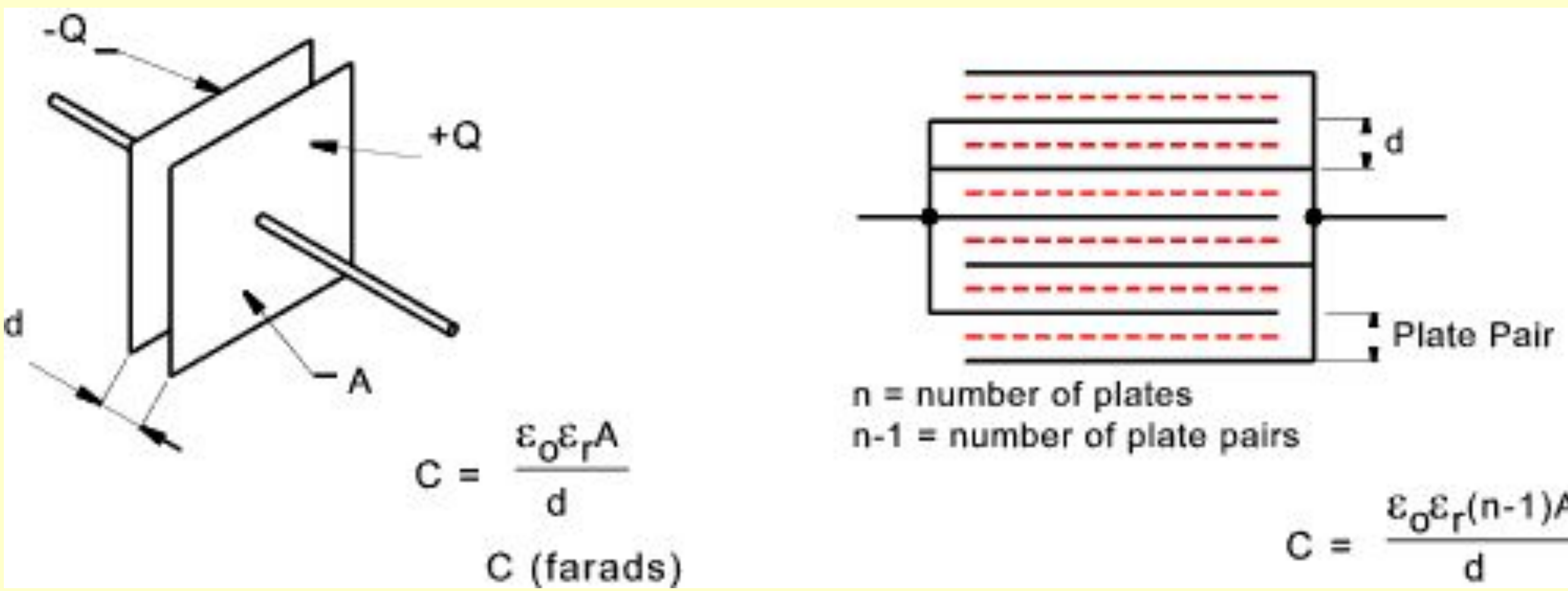
http://electronics.howstuffworks.com/iphone2.htm

- Capacitive touch-screens use a layer of capacitive material to hold an electrical charge; touching the screen changes the amount of charge at a specific point of contact.



Measuring Capacitance with reed switch



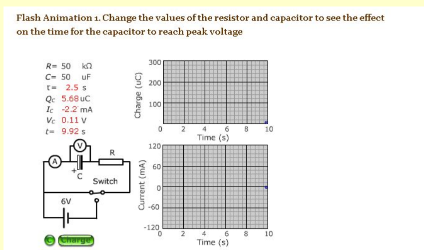

-Q
+Q
d
A
C = ε₀εᵣA / d
C (farads)
d
Plate Pair
n = number of plates
n-1 = number of plate pairs
C = ε₀εᵣ(n-1)A / d

Function of Dielectric

- The dielectrics contain charged molecules which are randomly oriented.
- When an external field is applied, by dropping a potential across the two plates, the charged molecules align themselves with the electric field (see Figure 2).
- This alignment of charges produces dipoles where the positive charges of each molecule are in the direction of the applied field and the negative charges oppose the field.
- An internal electric field, which is opposite in direction of the external electric field, will result.
- Consequently a reduction of the overall electric field and the overall potential occurs.
- Referring again to the definition of capacitance, if the potential across the two plates is reduced, the capacitance is increased.

Useful Websites

- http://www.splung.com/content/sid/3/page/capacitors



Picofarad (pF)	Nanofarad (nF)	Microfarad (uF)	Code	Picofarad (pF)	Nanofarad (nF)	Microfarad (uF)	Code
10	0.01	0.00001	100	4700	4.7	0.0047	472
15	0.015	0.000015	150	5000	5.0	0.005	502
22	0.022	0.000022	220	5600	5.6	0.0056	562
33	0.033	0.000033	330	6800	6.8	0.0068	682
47	0.047	0.000047	470	10000	10	0.01	103
100	0.1	0.0001	101	15000	15	0.015	153
120	0.12	0.00012	121	22000	22	0.022	223
130	0.13	0.00013	131	33000	33	0.033	333
150	0.15	0.00015	151	47000	47	0.047	473
180	0.18	0.00018	181	68000	68	0.068	683
220	0.22	0.00022	221	100000	100	0.1	104
330	0.33	0.00033	331	150000	150	0.15	154
470	0.47	0.00047	471	200000	200	0.2	254
560	0.56	0.00056	561	220000	220	0.22	224
680	0.68	0.00068	681	330000	330	0.33	334
750	0.75	0.00075	751	470000	470	0.47	474
820	0.82	0.00082	821	680000	680	0.68	684
1000	1.0	0.001	102	1000000	1000	1.0	105
1500	1.5	0.0015	152	1500000	1500	1.5	155
2000	2.0	0.002	202	2000000	2000	2.0	205
2200	2.2	0.0022	222	2200000	2200	2.2	225
3300	3.3	0.0033	332	3300000	3300	3.3	335

http://www.electronics-tutorials.ws/capacitor/cap_5.html

http://www.electronics2000.co.uk/calc/capacitor-code-calculator.php