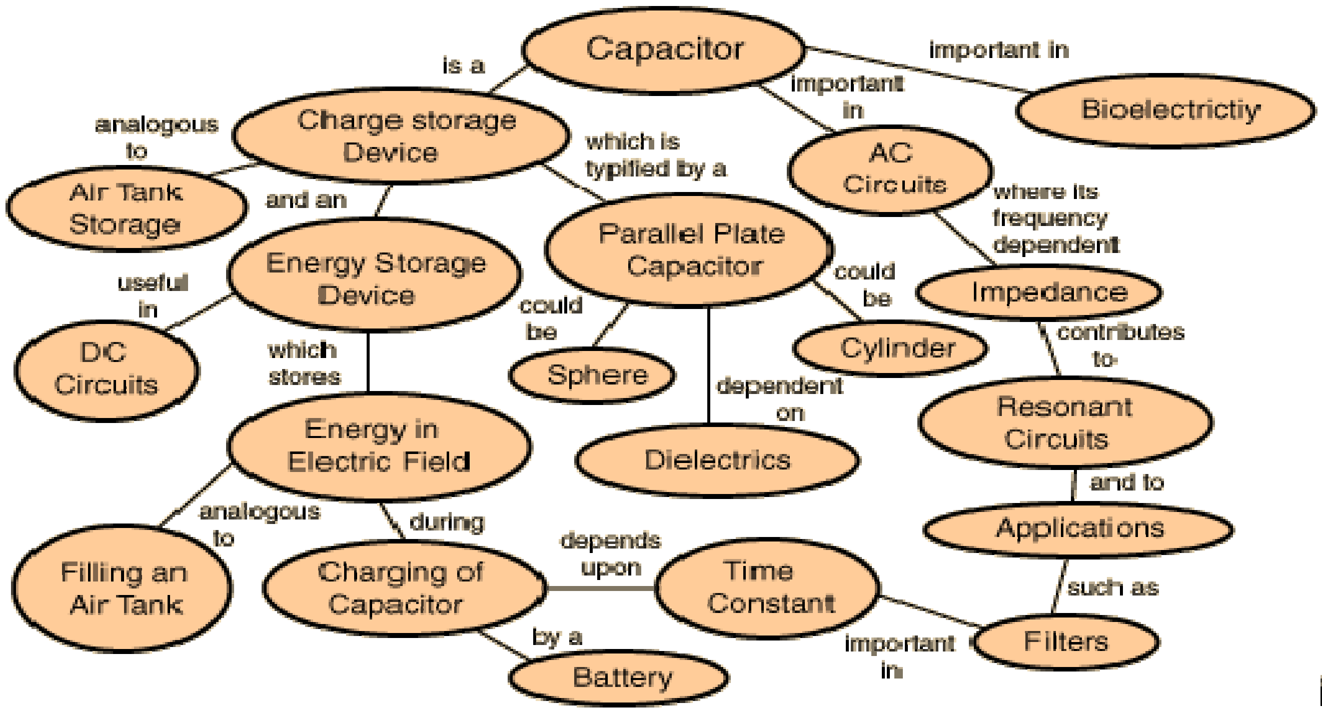
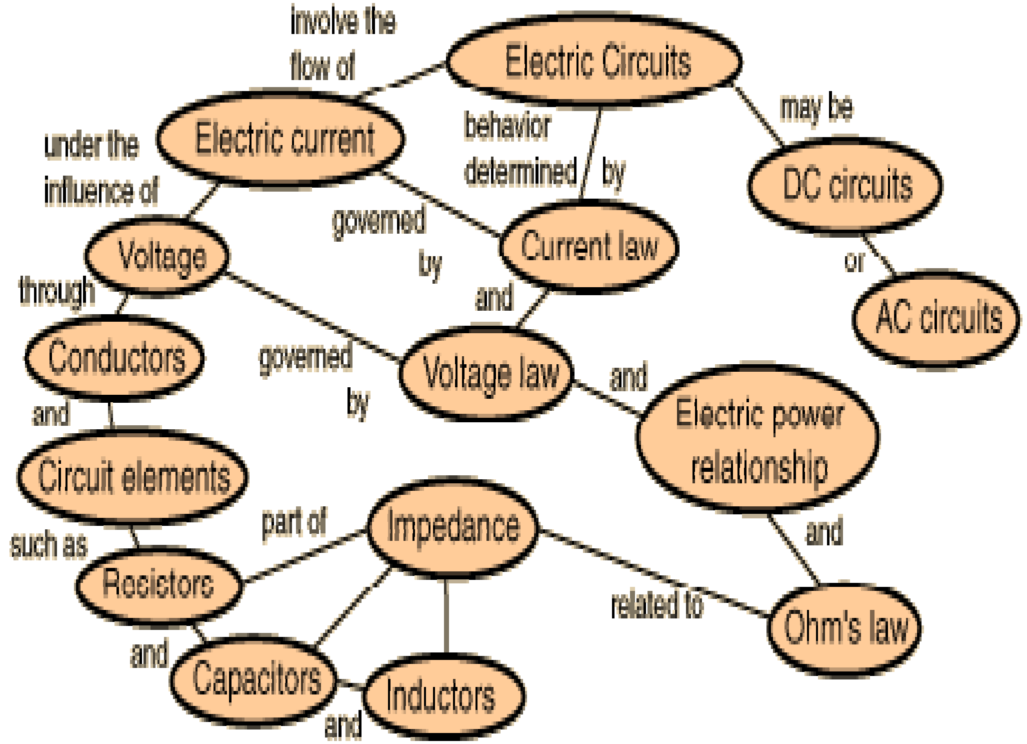

Capacitor
is a
important in
Bioelectrictiy
important in
Charge storage Device
analogous to
Air Tank Storage
and an
which is typified by a
AC Circuits
where its frequency dependent
Parallel Plate Capacitor
Energy Storage Device
useful in
DC Circuits
could be
Sphere
could be
Cylinder
Impedance
contributes to
which stores
Energy in Electric Field
dependent on
Dielectrics
Resonant Circuits
and to
Applications
analogous to
Filling an Air Tank
during
Charging of Capacitor
depends upon
Time Constant
such as
Filters
by a
Battery
important in


involve the flow of
Electric Circuits
may be
Electric current
under the influence of
behavior determined by
DC circuits
governed by
Current law
Voltage
or
AC circuits
through
and
Conductors
governed by
Voltage law
and
Electric power relationship
and
Circuit elements
such as
part of
Impedance
and
Resistors
related to
Ohm's law
and
Capacitors
Inductors
and

Capacitance definition of a system having a charge Q and a Potential V

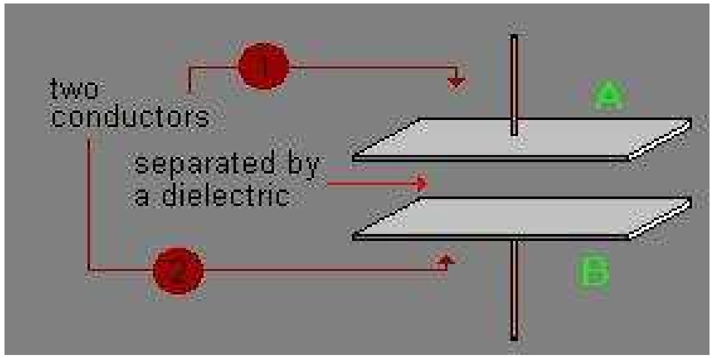
$$C = Q / V$$

In words: a measure of the electrical charge storing ability of a system

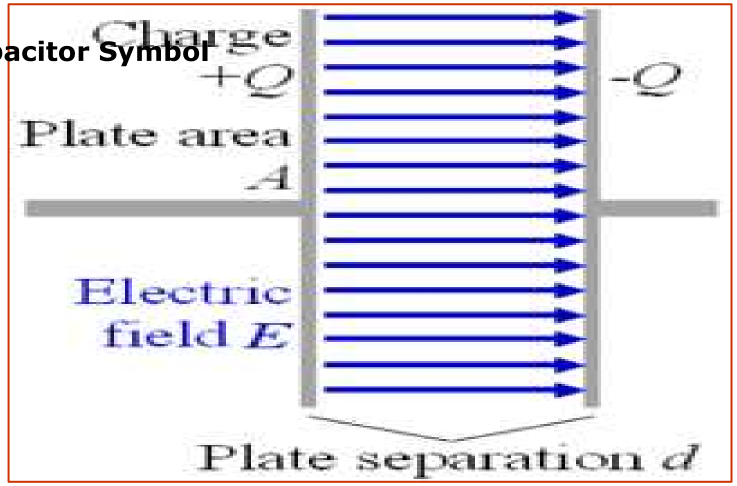
$$\text{Dimensions} = \text{charge/potential} = ml^2t^{-2}$$

The SI unit of capacitance is Farad; 1 farad = 1 coulomb/volt

Earliest unit = 'jar' (about 1 nF) from the use of Leyden jars



Capacitor Symbol



Parallel plate capacitor

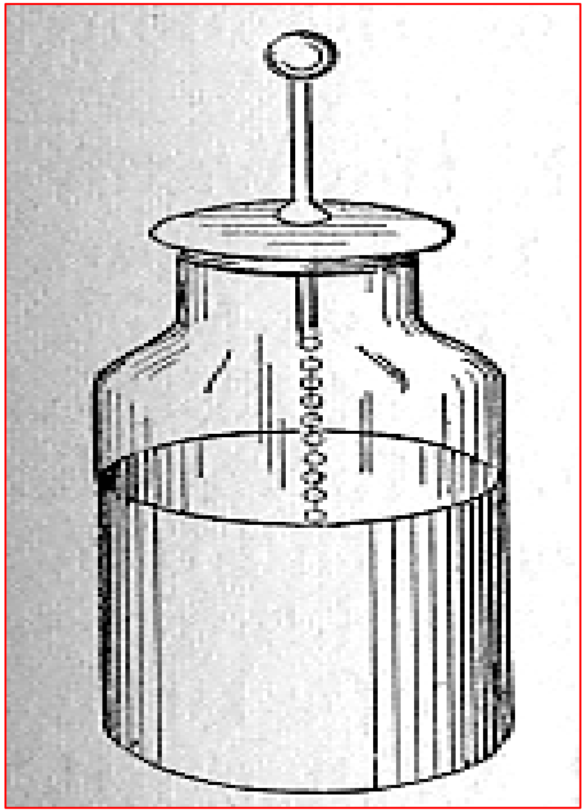
Capacitance definition of a system having a charge Q and a Potential V

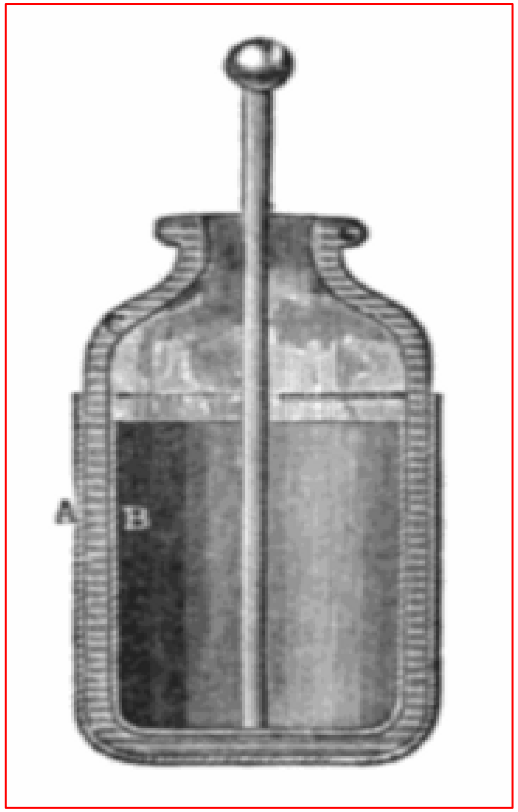
$$C = Q / V$$

In words: a measure of the electrical charge storing ability of a system

Unit = farad (F)

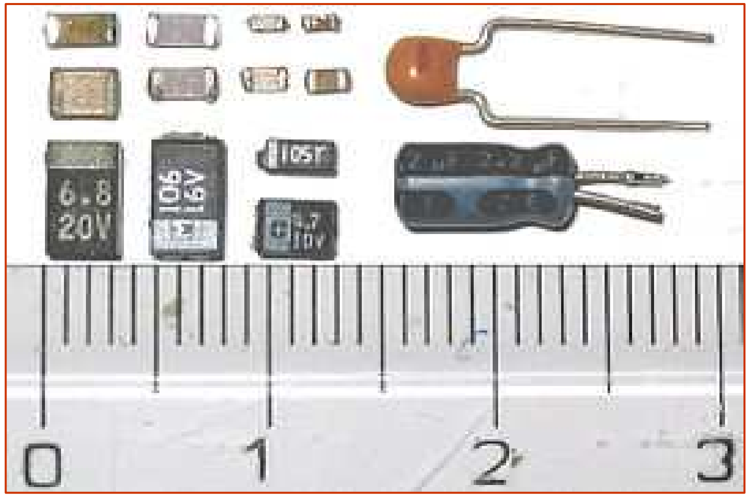
LEYDEN JAR the first capacitor (1745)

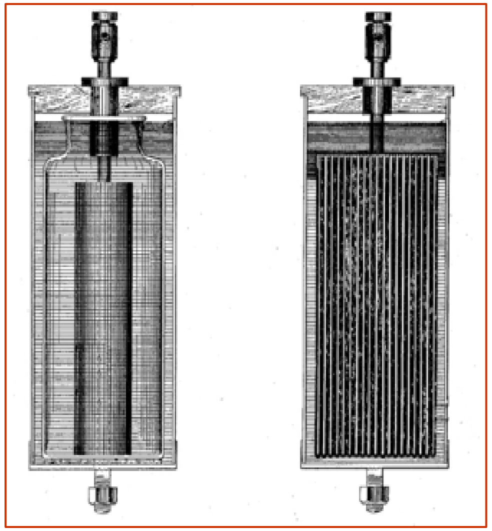


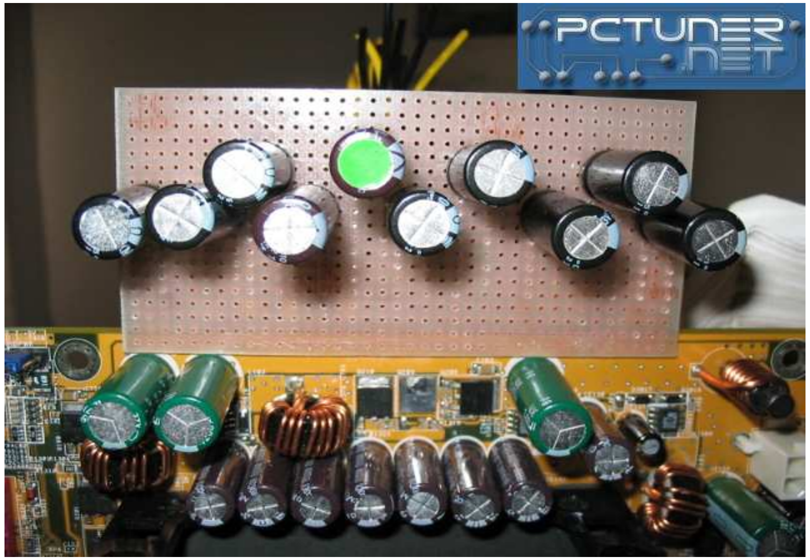


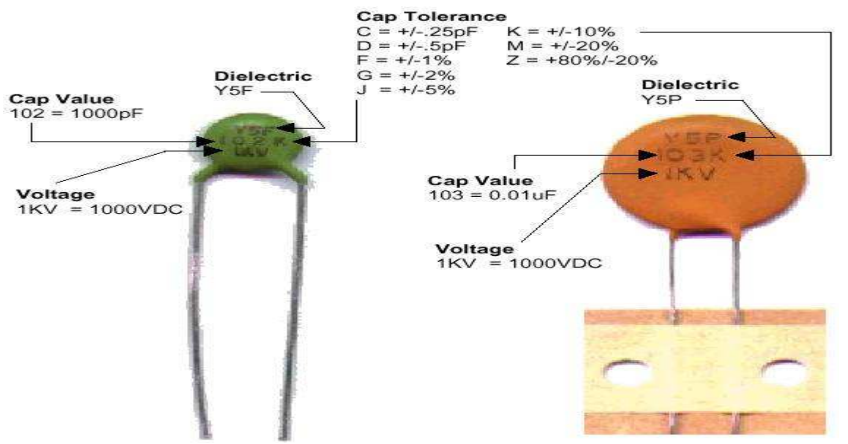
Capacitor and capacitance

$$C = Q/V$$

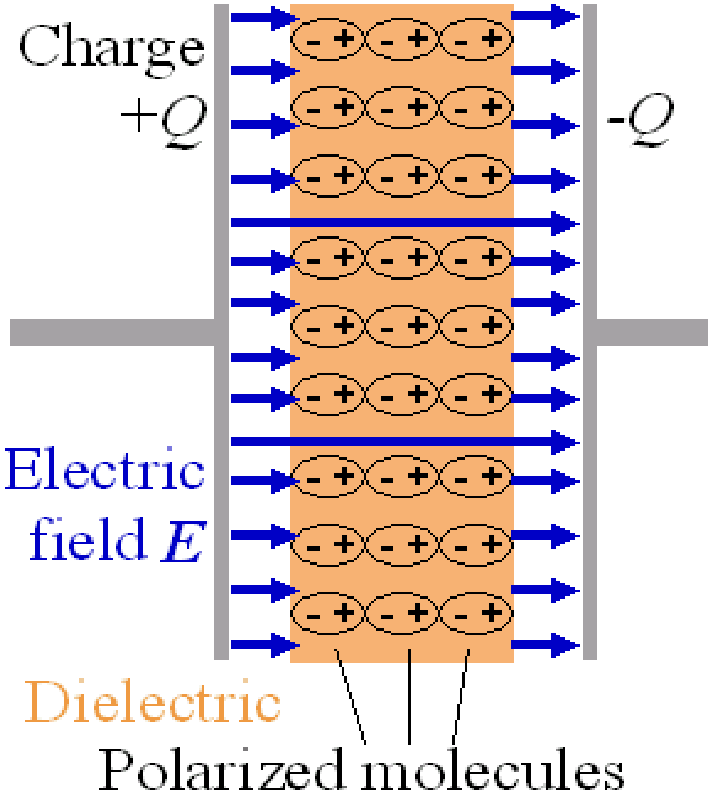








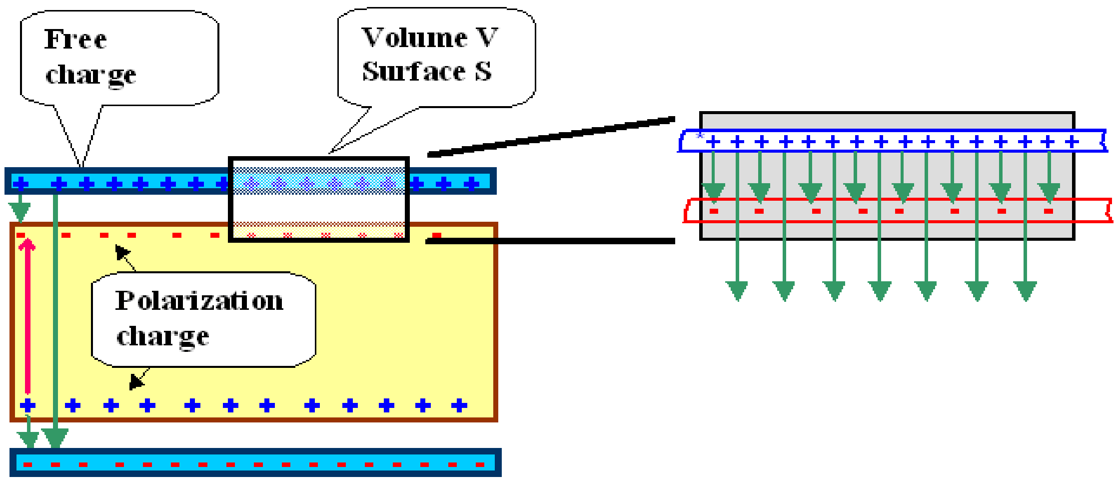
PARALLEL PLATE CAPACITOR

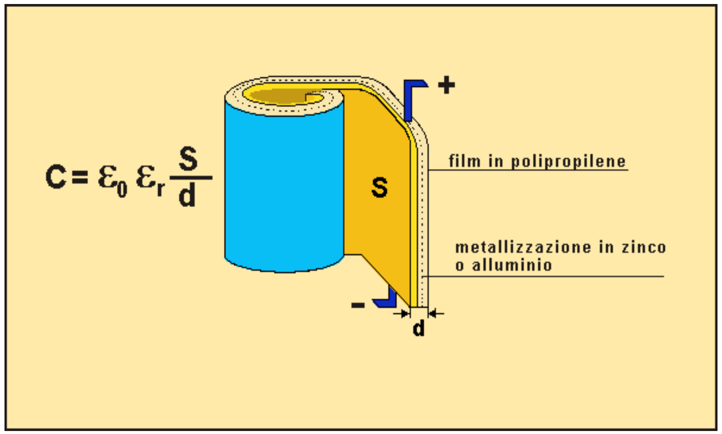


Gauss theorem

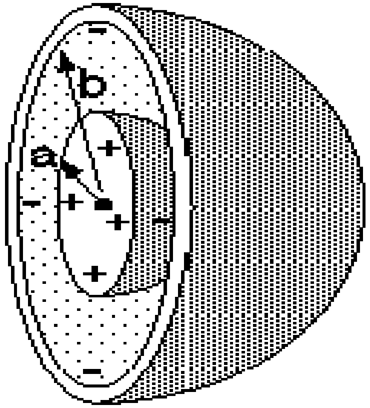
The flux of a vector field **F** out through a closed surface S equals the integral of the divergence of **F** over the region R bounded by S,

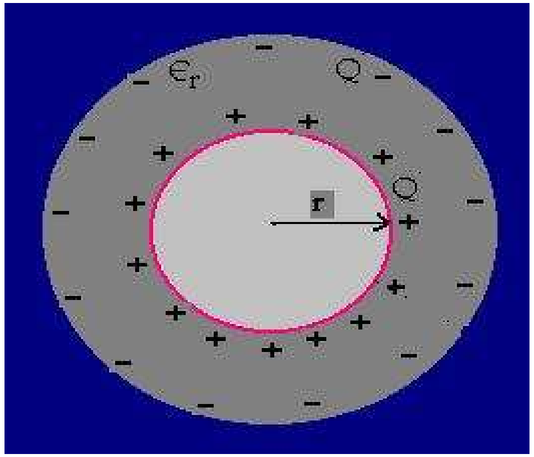
$$\iint_S \mathbf{F}\cdot\mathbf{n}\,dA = \iiint_R \operatorname{div}\mathbf{F}\,dV.$$





SPHERICAL CAPACITOR





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

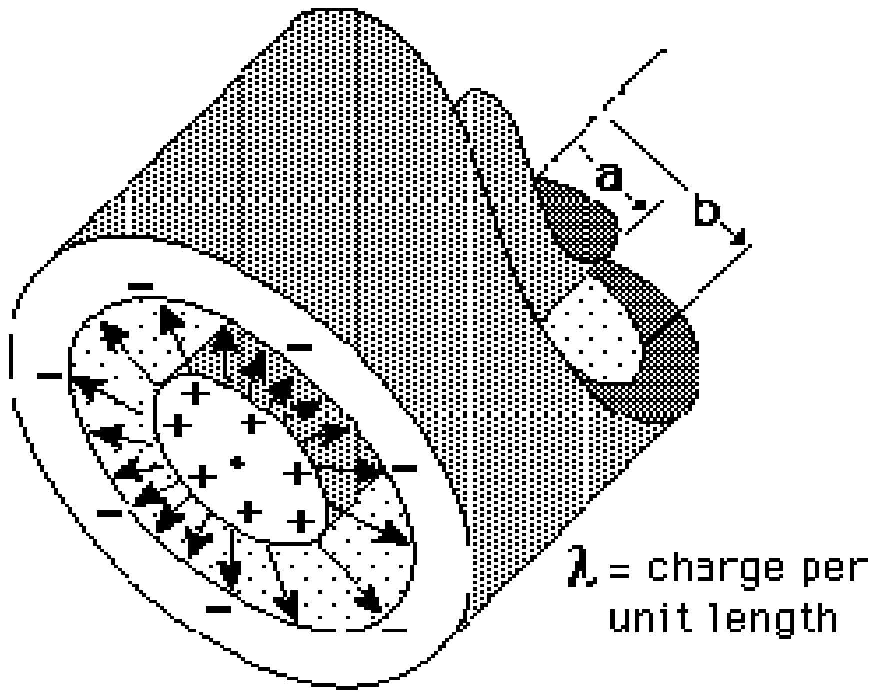
$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

$$\Delta V = \frac{Q}{4\pi\varepsilon_0}\int_a^b \frac{1}{r^2}dr = \frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{a} - \frac{1}{b}\right]$$ by integral

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

CILINDRICAL CAPACITOR

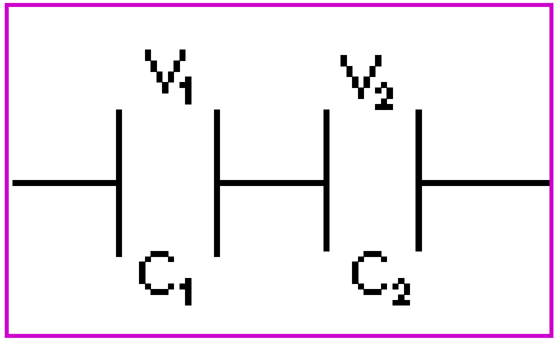
$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$ by Gauss theorem

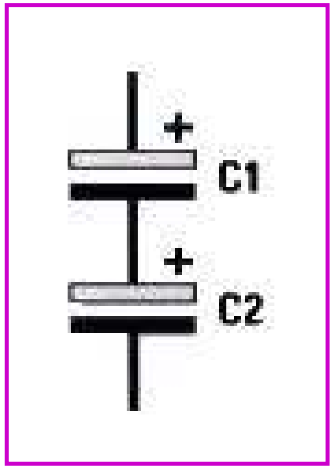


$$\Delta V = \frac{\lambda}{2\pi\varepsilon_0}\int_a^b \frac{1}{r}dr = \frac{\lambda}{2\pi\varepsilon_0}\ln\left[\frac{b}{a}\right]$$

by integral

$$\frac{C}{L} = \frac{\lambda}{\Delta V} = \frac{2\pi\varepsilon_0}{\ln\left[\frac{b}{a}\right]}$$





Two capacitors in series (of capacitance *C1* and *C2)* have the same charge *Q* stored on both, but a different voltage across each

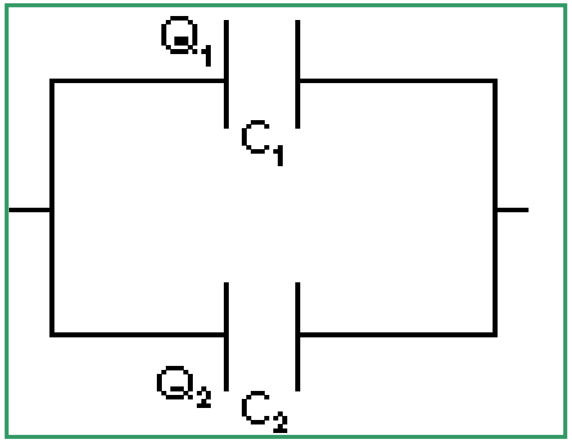
V = V1 + V2 = *Q/C1* + *Q/C2* = *Q/ C*

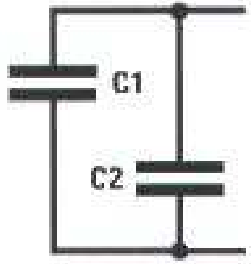
C is the combined capacitance

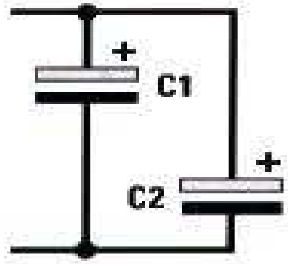
1/ C = 1/C1 + 1/C2

Series Capacitances

$$C_{\text{total}} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \ldots \frac{1}{C_n}}$$







Two capacitors in parallel (of capacitance *C1* and *C2)* have the same potential difference across each, but a different charge *Q*

Q = Q1 + Q2 = *V/C1* + *V/C2* = *V/ C*

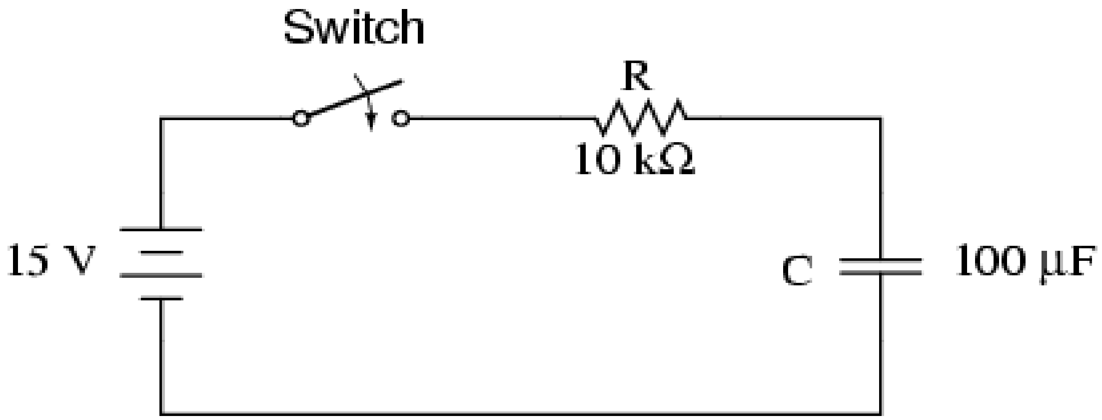
C is the combined capacitance

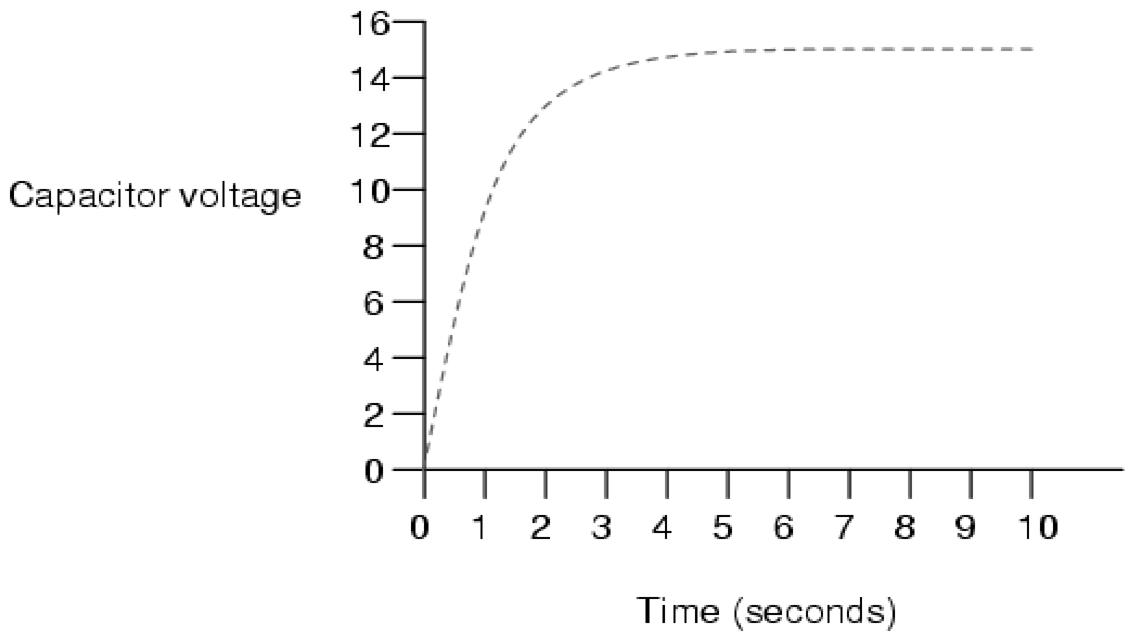
C = C1 + C2

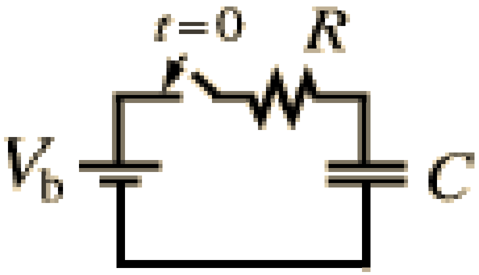
Parallel Capacitances

$$C_{\text{total}} = C_1 + C_2 + \ldots C_n$$

CHARGING A CAPACITOR







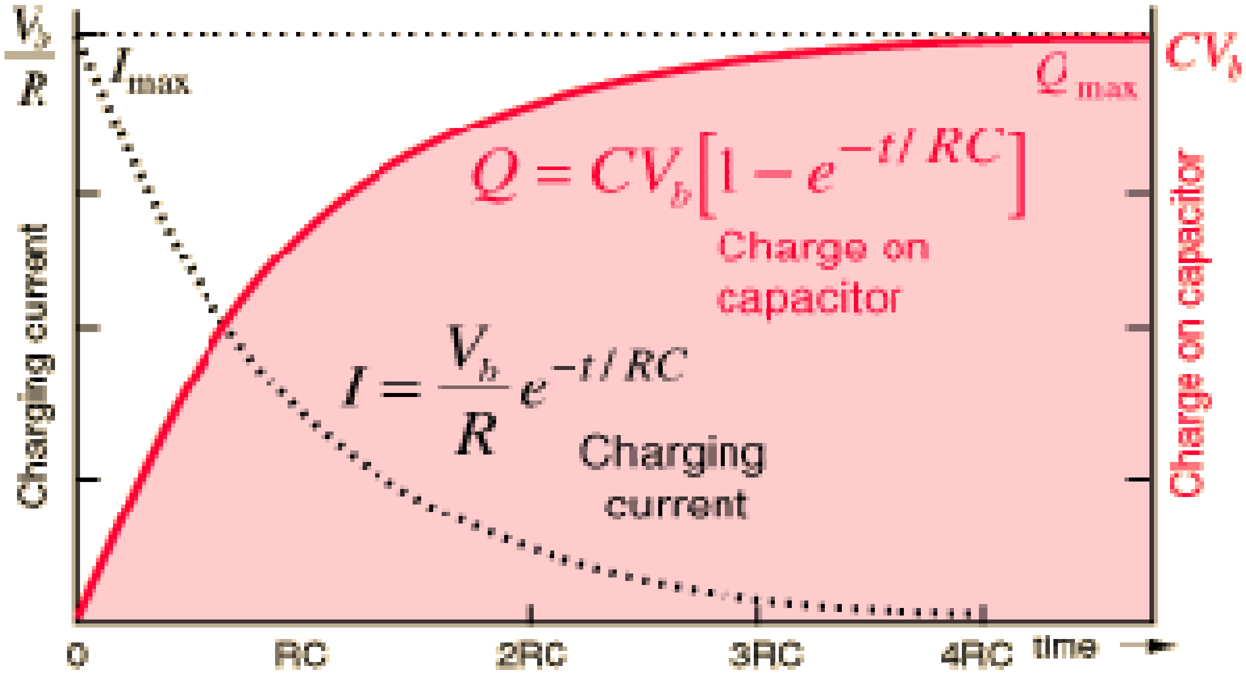
$$V_b = V_R + V_C$$

$$V_b = IR + \frac{Q}{C}$$

As charging progresses,

$$V_b = IR + \frac{Q}{C}$$

current decreases and charge increases.



At $t = 0$

$Q = 0$

$V_C = 0$

$I = \frac{V_b}{R}$

As $t \to \infty$

$Q \to CV_b$

$V_C \to V_b$

$I \to 0$

Stored energy in a capacitor

$$\mathrm{d}W = \frac{q}{C}\,\mathrm{d}q$$

charging an ammount dq

$$\mathrm{E} = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}VQ$$

Electric field

$$W_{charging} = \int_0^Q \frac{q}{C}\,\mathrm{d}q = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = W_{stored}$$

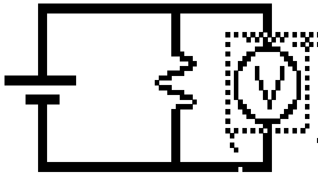
$$W_{stored} = \frac{1}{2}CV^2 = \frac{1}{2}\epsilon\frac{A}{d}V^2$$

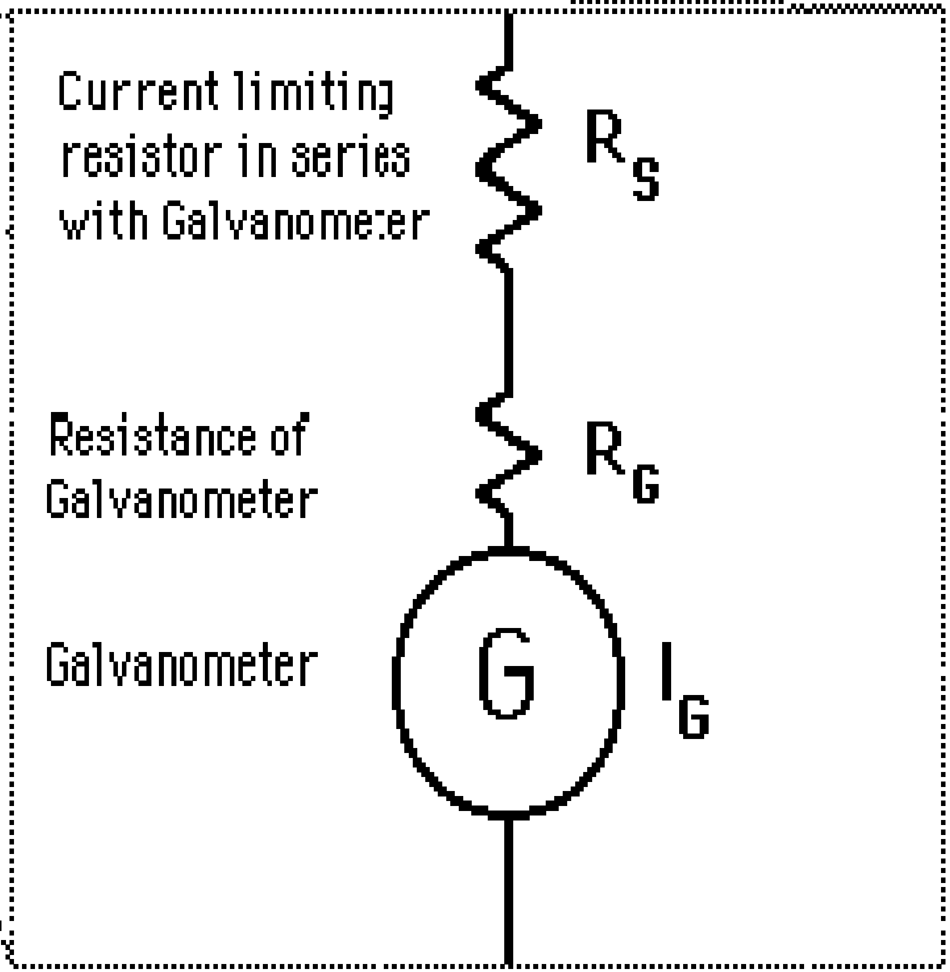
Parallel plate capacitor

Time Constant for Transients

		Time Constant
Charging of a capacitor	$Q = CV_b\left[1 - e^{\frac{-t}{RC}}\right]$	$\tau = RC$
Current buildup in an inductor	$I = \frac{V_b}{R}\left[1 - e^{\frac{-t}{L/R}}\right]$	$\tau = L/R$

Design voltage V

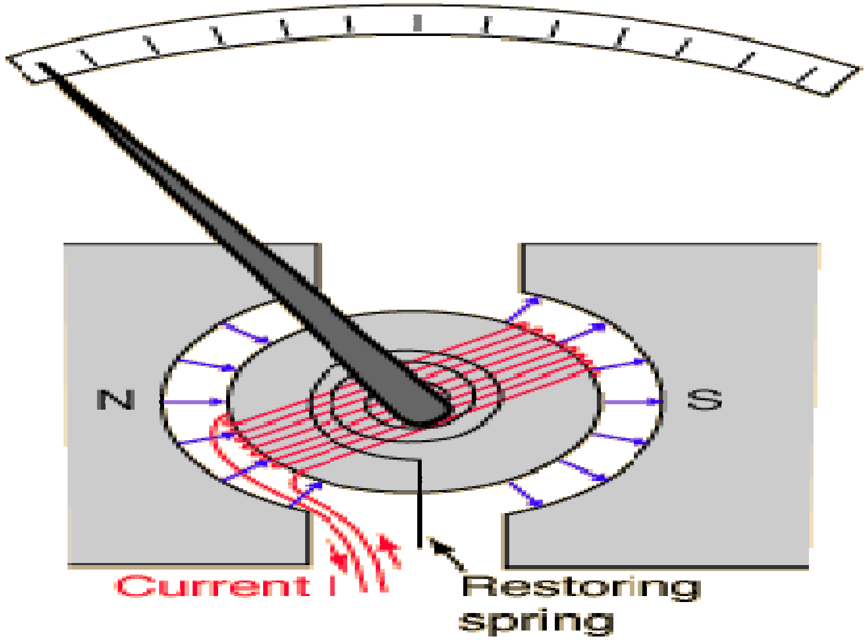


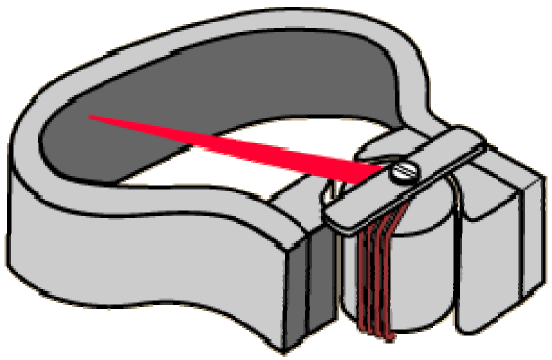


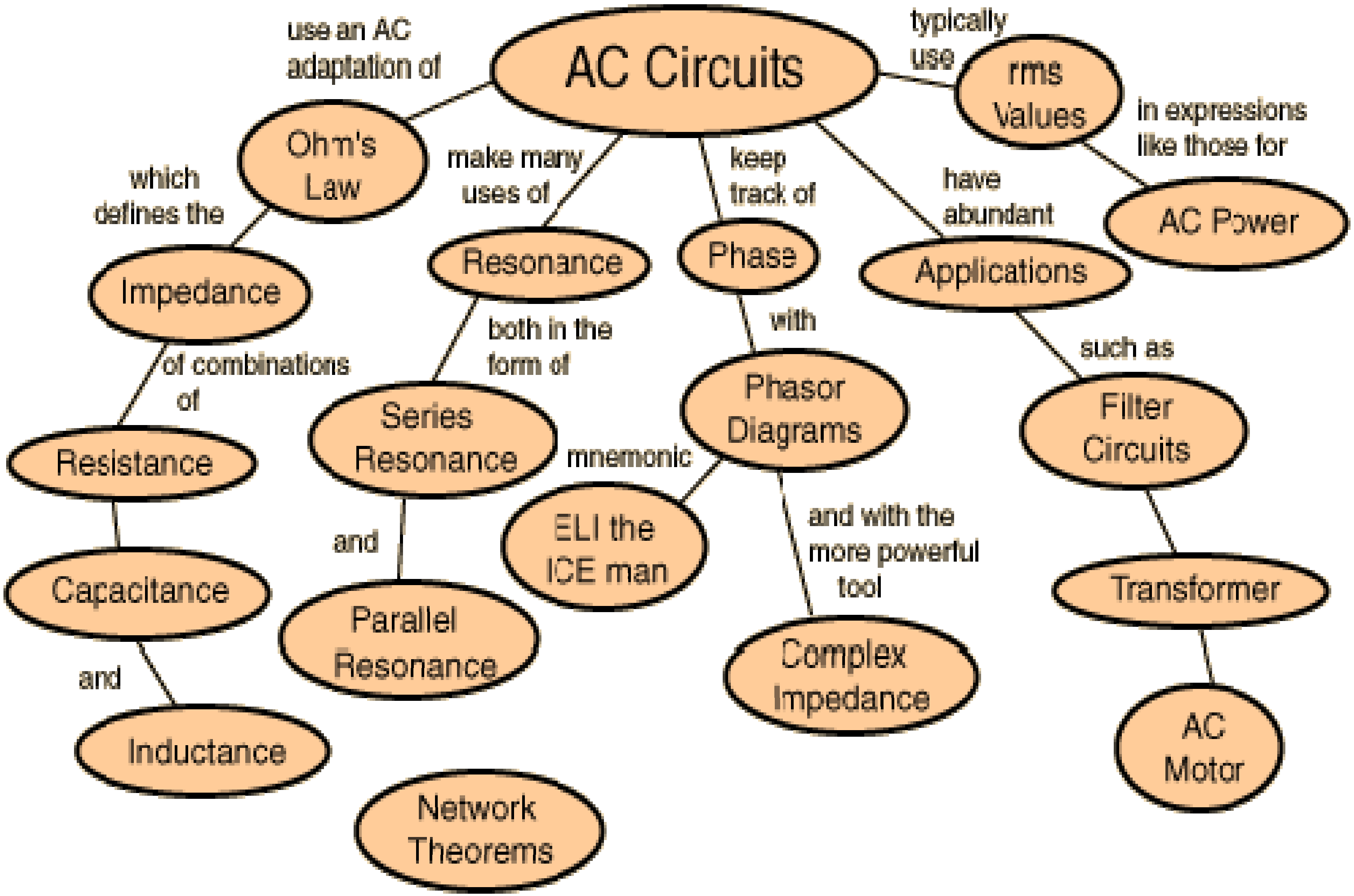
Design task: Given the resistance and the current which causes full scale reading on the galvanometer, find the value of the series current-limiting resistor which will give full scale reading with the design voltage of the voltmeter.

I_G is the current to give full scale reading

Galvanometer






AC Circuits
use an AC adaptation of
Ohm's Law
which defines the
Impedance
of combinations of
Resistance
Capacitance
and
Inductance
make many uses of
Resonance
both in the form of
Series Resonance
and
Parallel Resonance
Network Theorems
keep track of
Phase
with
Phasor Diagrams
mnemonic
ELI the ICE man
and with the more powerful tool
Complex Impedance
typically use
rms Values
in expressions like those for
AC Power
have abundant
Applications
such as
Filter Circuits
Transformer
AC Motor

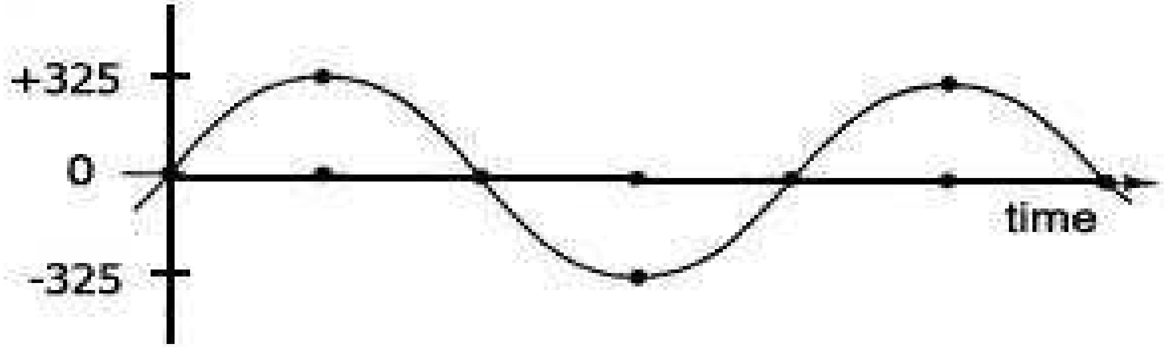
'root mean square' (rms) Voltage

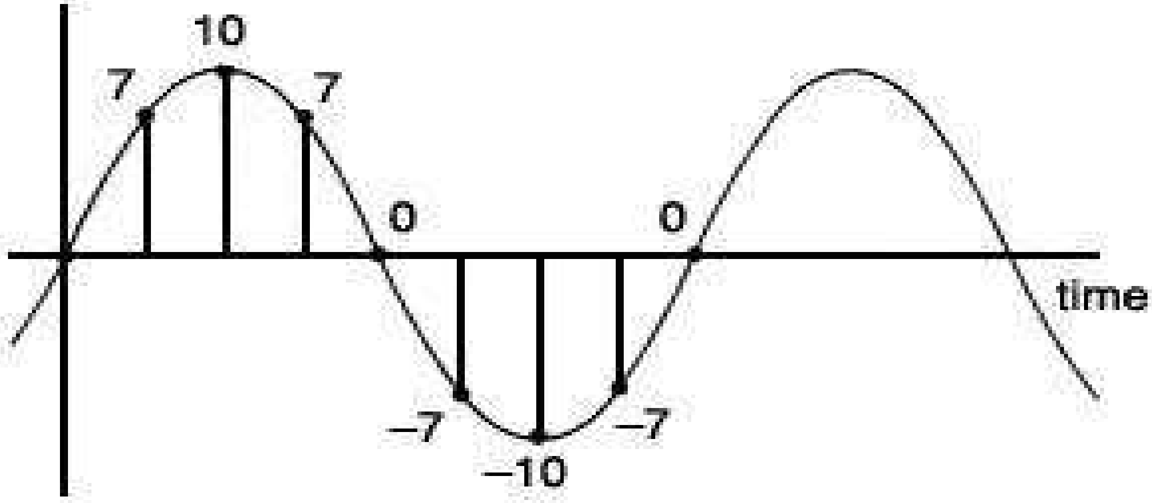
rms average =

(*peak value*) / √2 =

***peak value*/1.41 =**

0.707 *peak value*



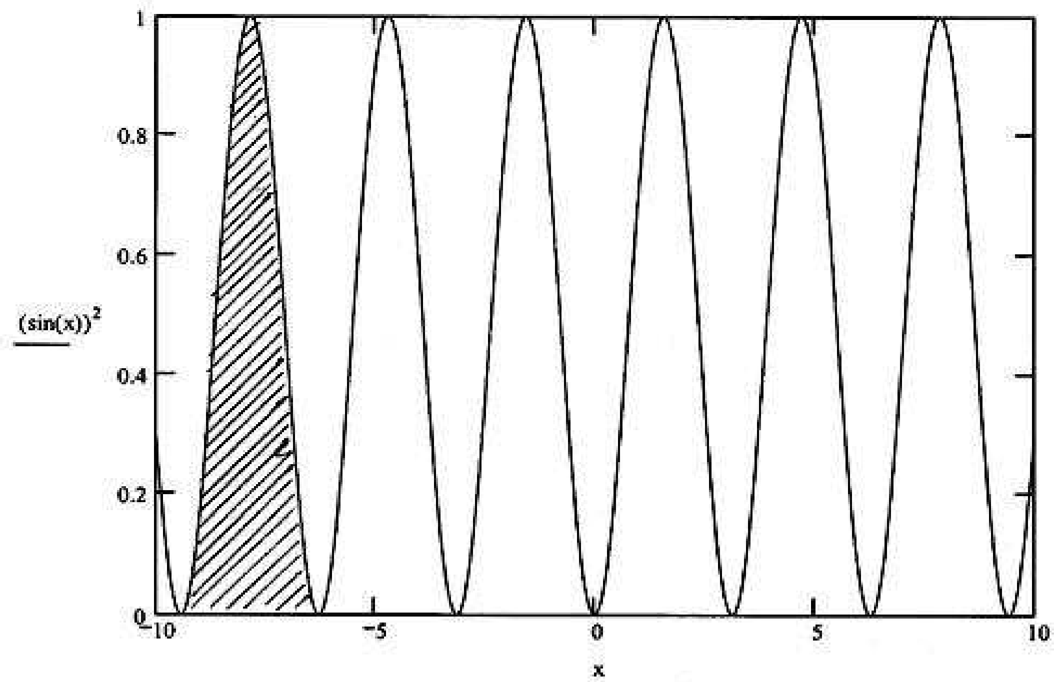


'root mean square' (rms) Current: another method

$$I = I_o \sin \omega t \qquad I^2 = Io^2 \sin^2 \omega t$$

Heating effect depends on $I^2 R$

an average of both I^2 and sin^2 is needed

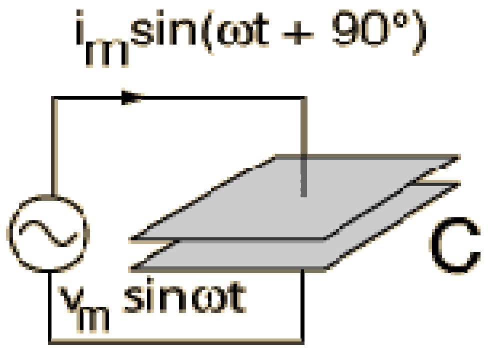


$$\sin^2 \omega t + \cos^2 \omega t = 1$$

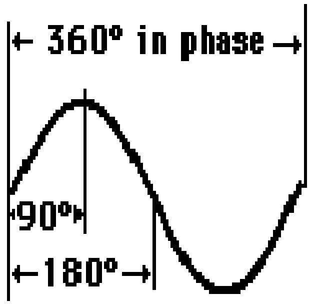
The average values of either of them must be 1/2

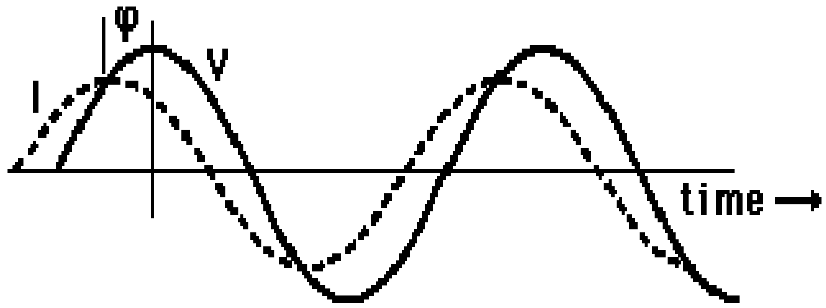
rms value of $I_o \sin \omega t = I_o / \sqrt{2}$

Capacitor AC Response

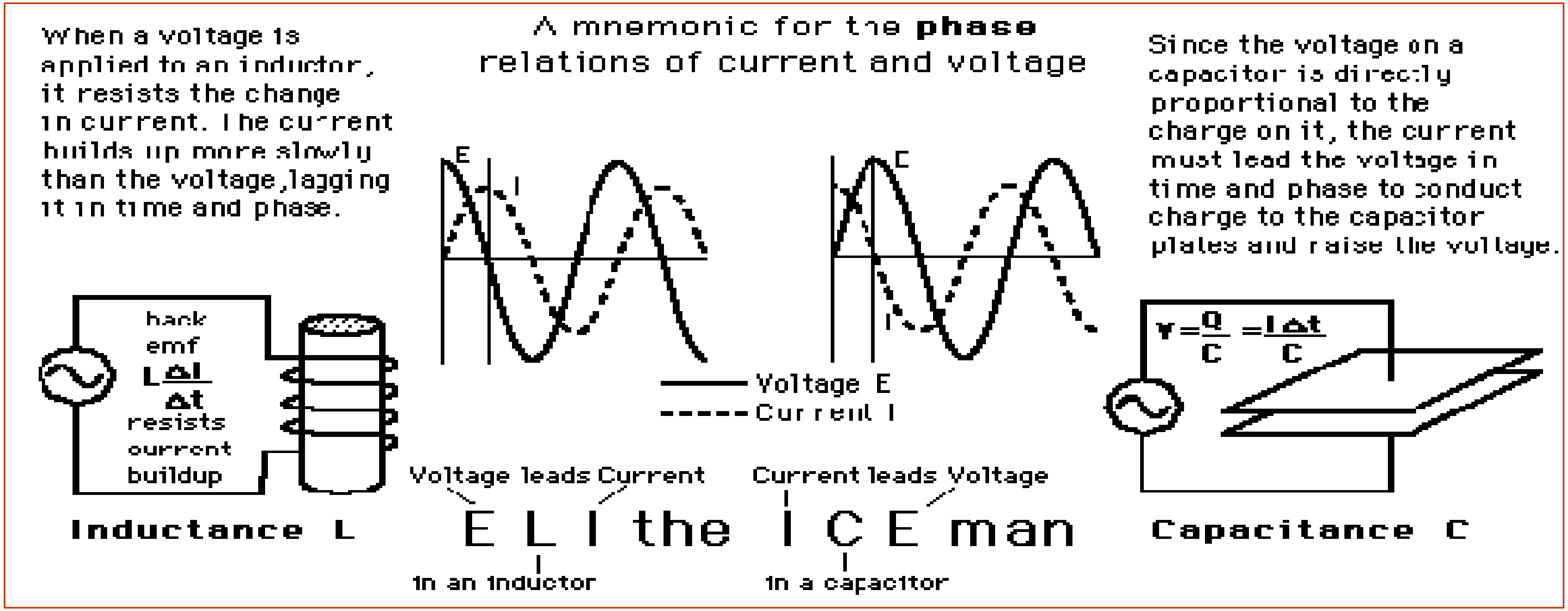


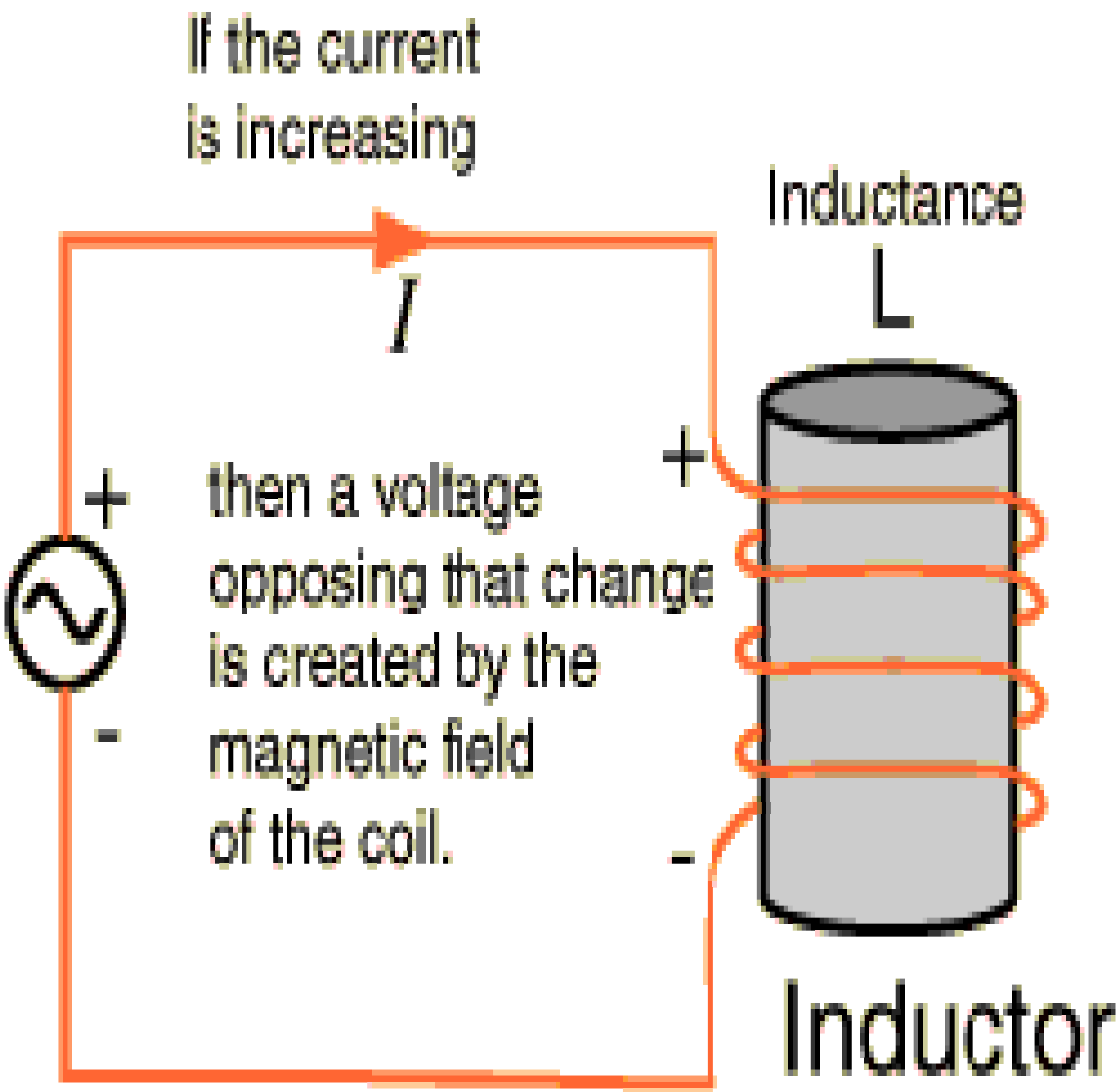
$$I = \frac{I_m}{\sqrt{2}}, V = \frac{V_m}{\sqrt{2}}$$





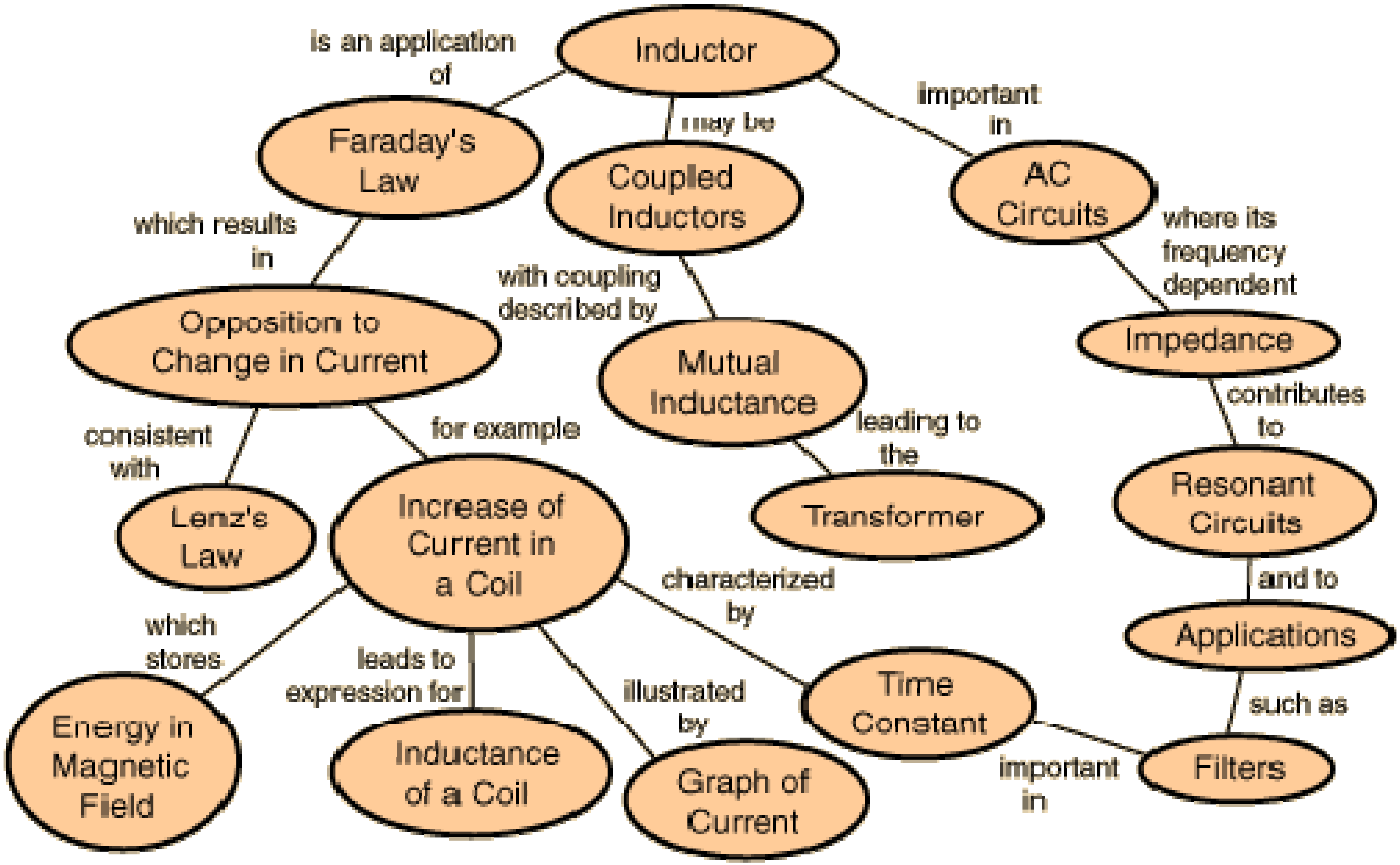
The current I leads the voltage V in phase by angle φ. This implies a capacitive circuit.





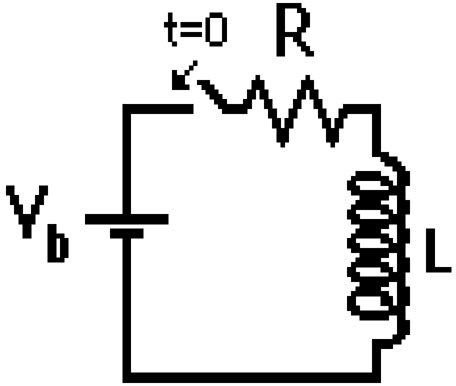
$$\text{Emf} = -L\frac{\Delta I}{\Delta t}$$

$$\text{Unit: } \frac{\text{volt second}}{\text{ampere}} = \text{henry}$$



Inductor
is an application of
Faraday's Law
may be
Coupled Inductors
important in
AC Circuits
which results in
Opposition to Change in Current
with coupling described by
Mutual Inductance
where its frequency dependent
Impedance
contributes to
Resonant Circuits
and to
Applications
such as
Filters
consistent with
Lenz's Law
for example
Increase of Current in a Coil
leading to the
Transformer
characterized by
Time Constant
important in
which stores
Energy in Magnetic Field
leads to expression for
Inductance of a Coil
illustrated by
Graph of Current

Inductor Transient



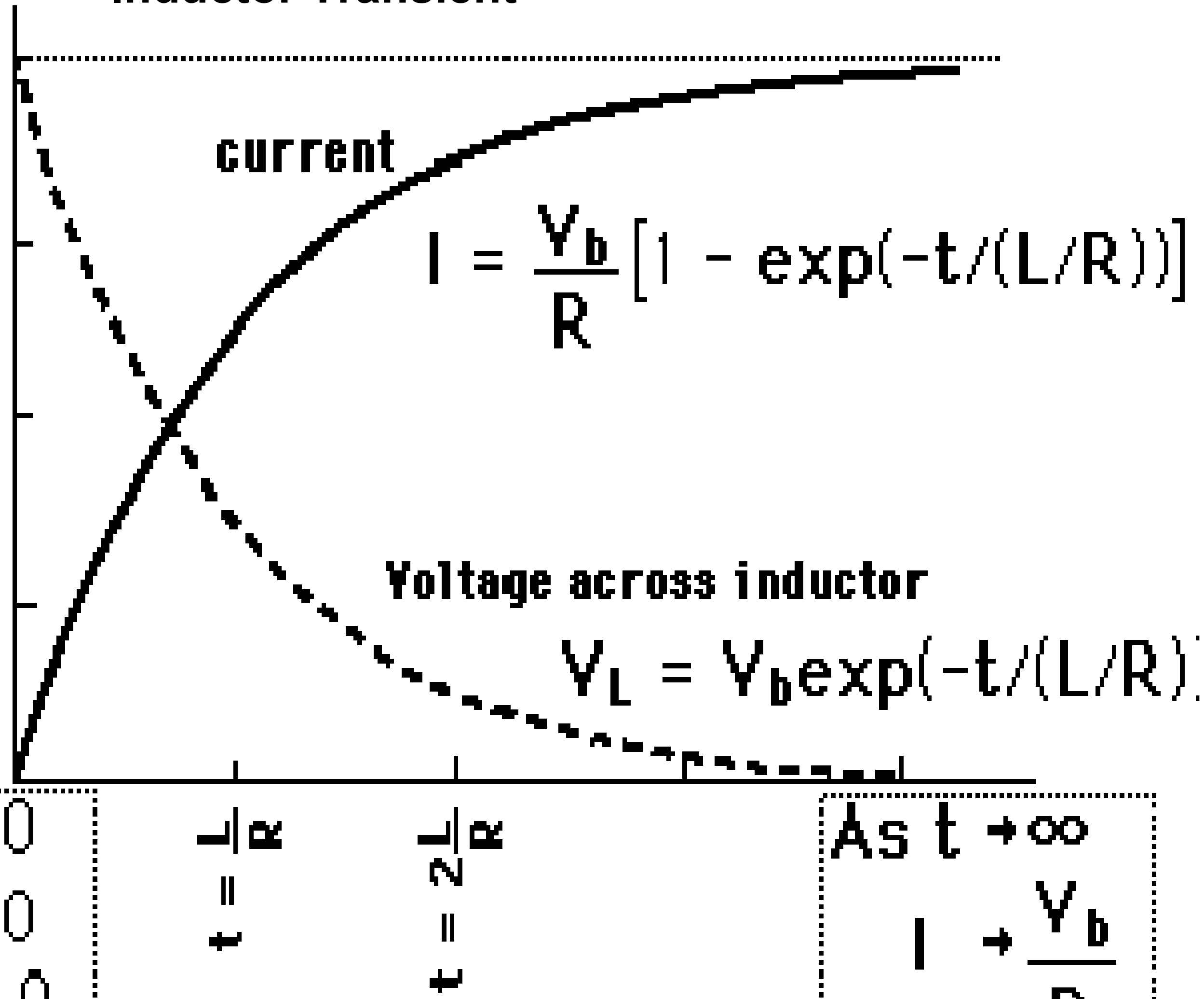
$$V_b = V_R + V_L$$

$$V_b = IR + L\frac{\Delta I}{\Delta t}$$

As the current increases

$$V_b = IR\uparrow + L\frac{\Delta I}{\Delta t}\downarrow$$

the rate of change of current decreases.



at $t=0$

$I = 0$

$V_R = 0$

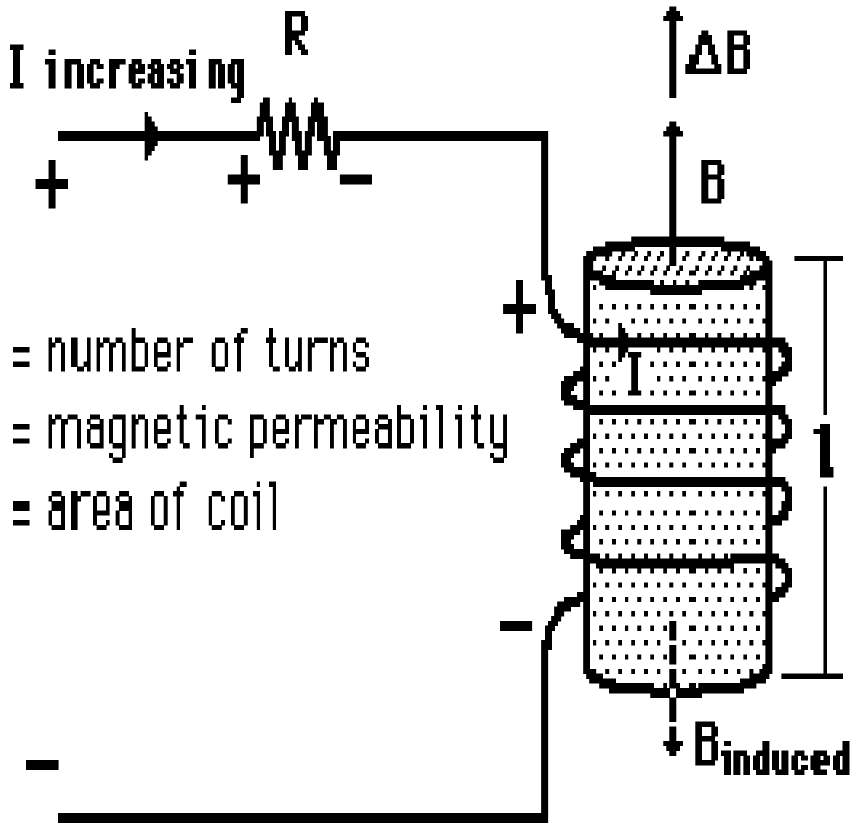
$V_L = V_b$

As $t \to \infty$

$I \to \frac{V_b}{R}$

$V_R \to V_b$

Inductance of a Coil



N = number of turns

μ = magnetic permeability

A = area of coil

$$\text{Emf} = -N\frac{\Delta\Phi}{\Delta t} = -NA\frac{\Delta B}{\Delta t}$$

$$B = \mu\frac{N}{l}I$$

$$\text{Emf} = -\frac{\mu N^2 A}{l}\frac{\Delta I}{\Delta t}$$

$$\text{Emf} = -L\frac{\Delta I}{\Delta t}$$

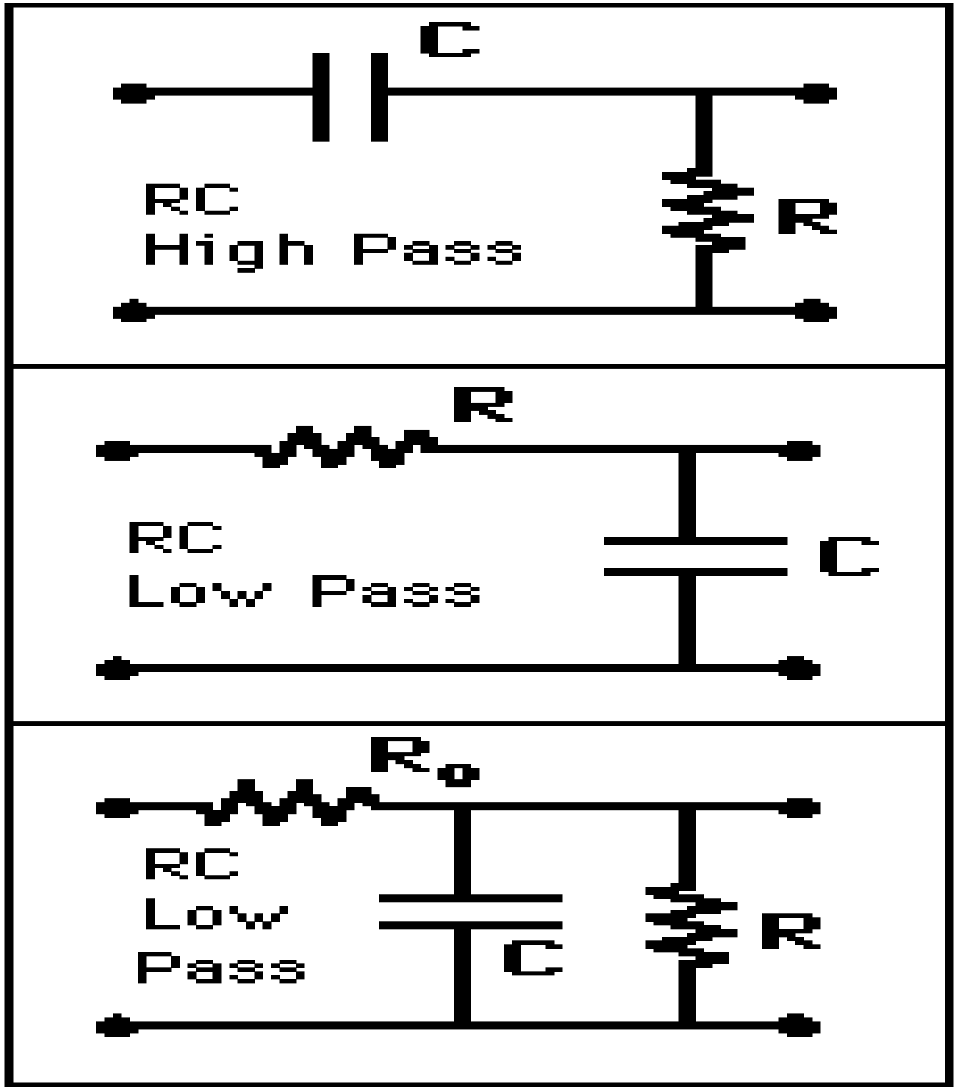
$$L = \frac{\mu N^2 A}{l}$$

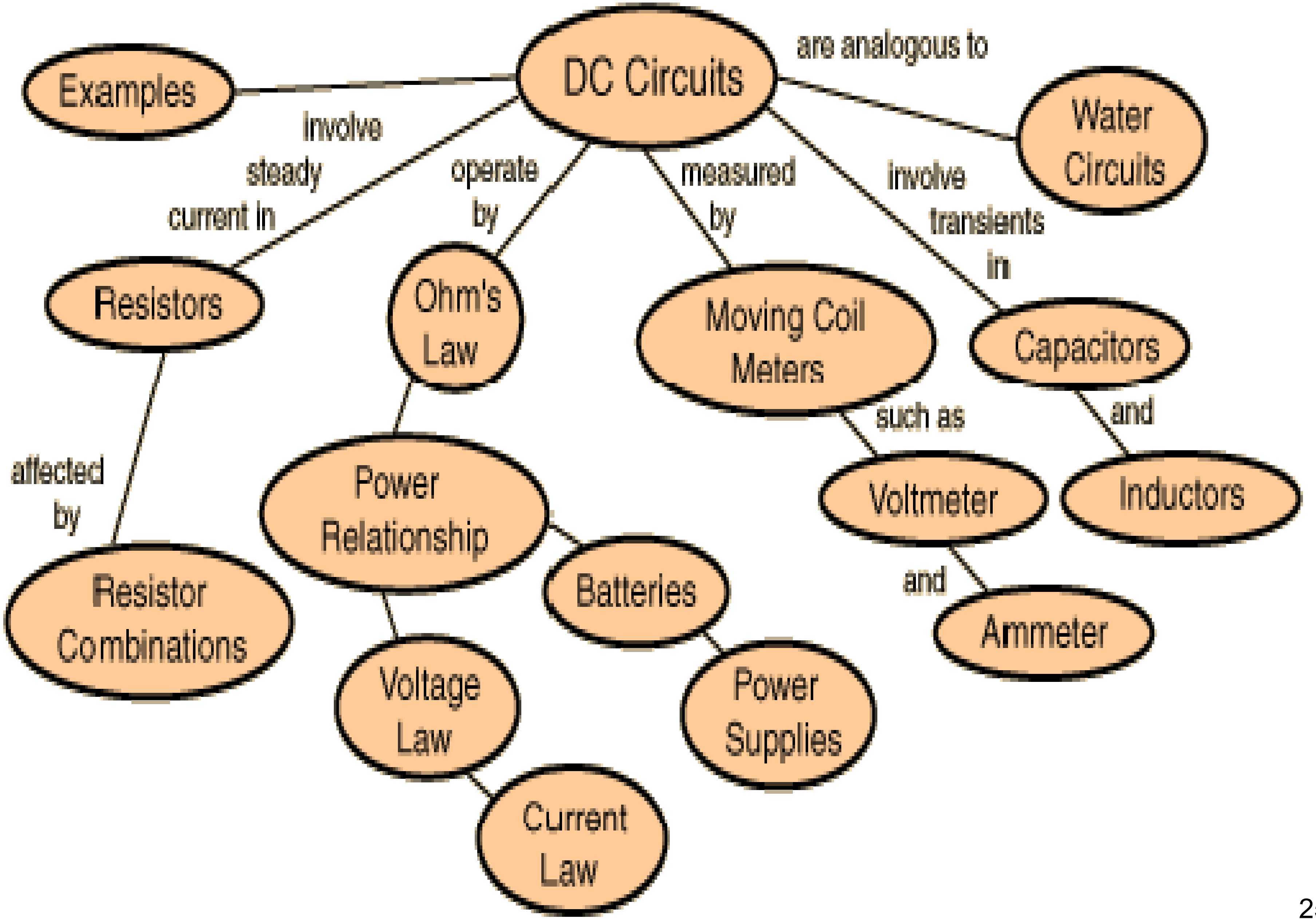
$$V = IR + L\frac{\Delta I}{\Delta t}$$

The Emf opposes the applied voltage

Application of **voltage law.**

Filter Circuits made with Resistors and Capacitors




DC Circuits
Examples
are analogous to
Water Circuits
involve steady current in
Resistors
operate by
Ohm's Law
measured by
Moving Coil Meters
involve transients in
Capacitors
and
Inductors
such as
Voltmeter
and
Ammeter
affected by
Resistor Combinations
Power Relationship
Batteries
Power Supplies
Voltage Law
Current Law