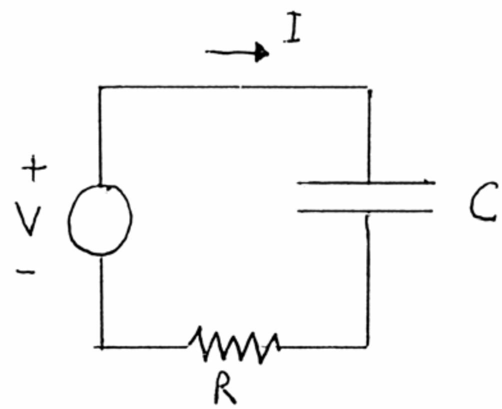
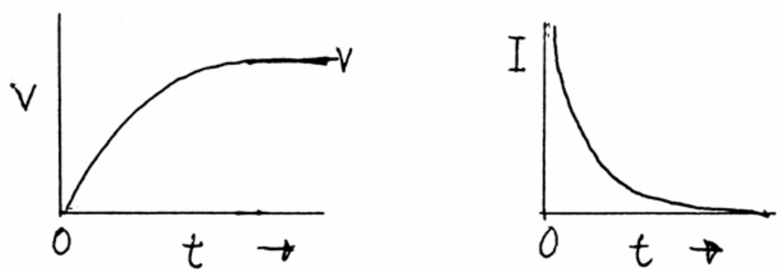
Capacitors in Circuits

- Capacitors store energy in the electric field
- E field created by the stored charge
- In circuit Capacitor may be absorbing energy
- Thus causes circuit current to be reduced
- Effectively becomes a voltage source
- If C charged and no V may supply current from E field
- Depends on condition of circuit
- Will see this in Resistor Capacitor (RC) circuits





Capacitors in Parallel

- Capacitors in parallel act just like one large capacitor
- Each capacitor has same voltage on it
- Hence plates one are just extensions of those on other C's
- They are connected by the parallel connection wire
- Do not need the plates to be continous
- Capacitors in parallel add to the total capacitance

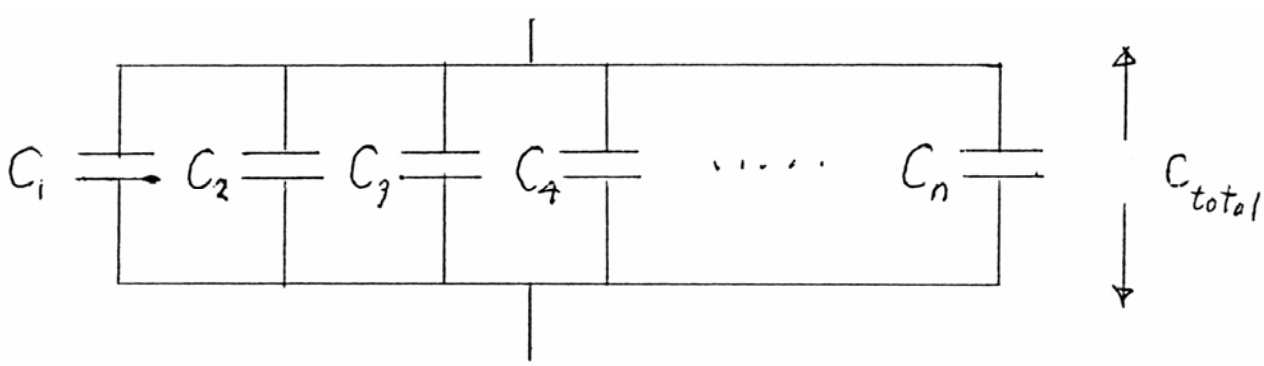
$$C_{total} = \sum_{j=1}^{n} C_j$$

- "Capacitors in parallel act like resistors in Series"

- Example: total of 1, 2, and 3 μF capacitors in parallel

Thus total is

$$C_{total} = \sum_{j=1}^{n} C_j = C_1 + C_2 + C_3 = 10^{-6} + 2 \times 10^{-6} + 3 \times 10^{-6} = 6\ \mu F$$



Capacitors in Series

- In series capacitors decrease value
- "Capacitors in series act like resistors in Parallel"
- Inverse of the total equals the sum of the inverses of n capacitors

$$\frac{1}{C_{total}} = \sum_{j=1}^{n} \frac{1}{C_j}$$

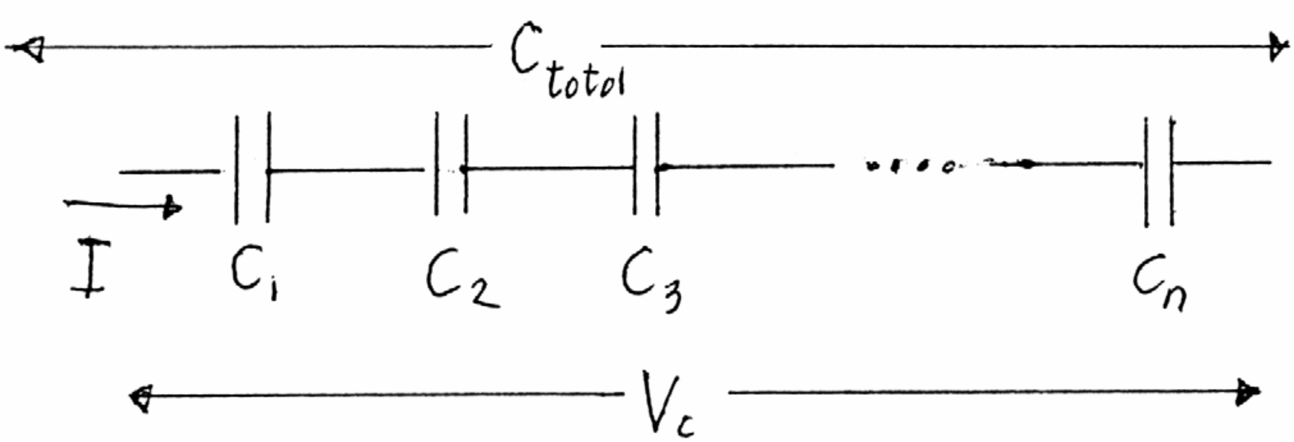
- Why do Capacitors act different: Consider a series of C's
- In series the current through each capacitor is the same.
- Recall the voltage is given by:

$$V = \frac{1}{C} \int I(t)dt$$

- Thus by KVL the total voltage across the capacitors is:

$$V_{total} = \sum_{j=1}^{n} V_j = \sum_{j=1}^{n} \left[\frac{1}{C_j} \int I(t)dt \right] = \left[\sum_{j=1}^{n} \frac{1}{C_j} \right] \int I(t)dt$$

- Where t is the time of measurement



Series Capacitors

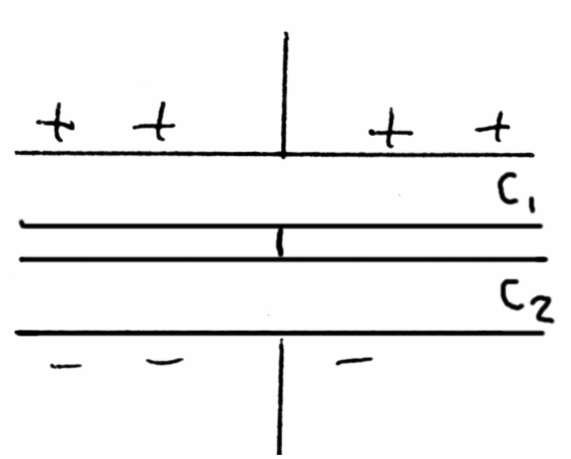
- Actually like adding up the spacing between all the C's plates
- If d_j is plate thickness of C_j then

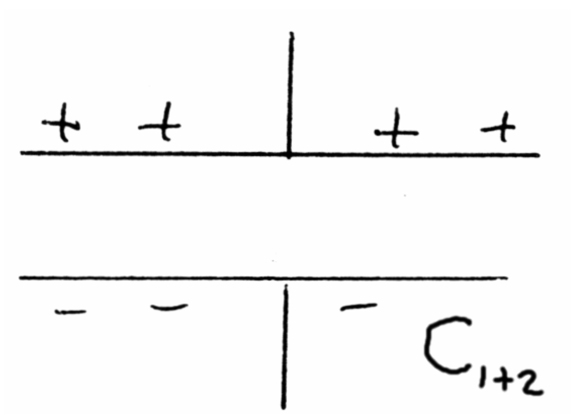
$$d_{total} = \sum_{j=1}^{n} d_j$$

Recall that C is controlled by E field
E field goes inversely with distance between plates.

$$\vec{E} = \frac{V}{\vec{d}}$$

Thus if put 2 C's of same value in series get half the C





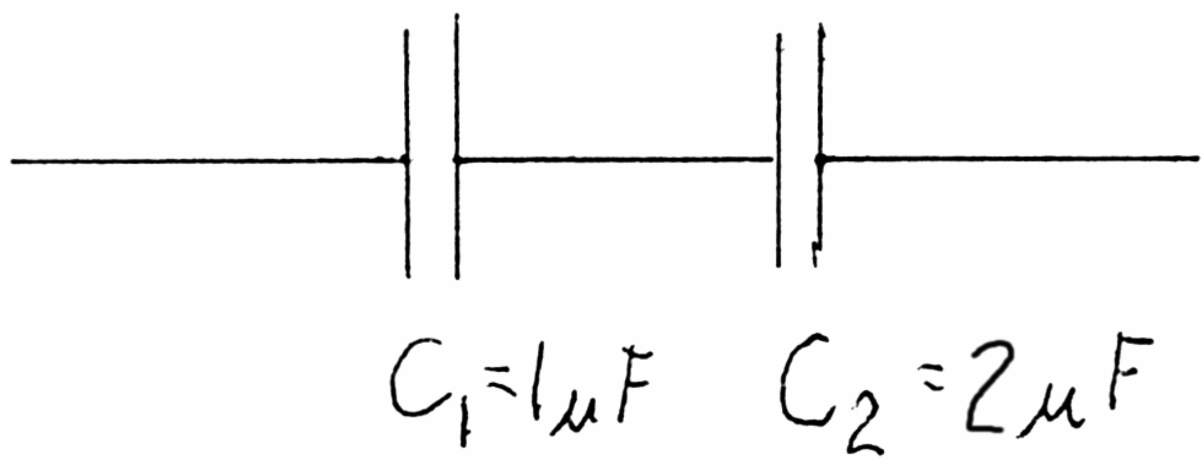
Example Series Capacitors

- Example: $C_1 = 1\ \mu F$ and $C_2 = 2\ \mu F$ capacitors in series
- Thus total is

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{10^{-6}} + \frac{1}{2\times 10^{-6}} = \frac{3}{2\times 10^{-6}}\ F$$

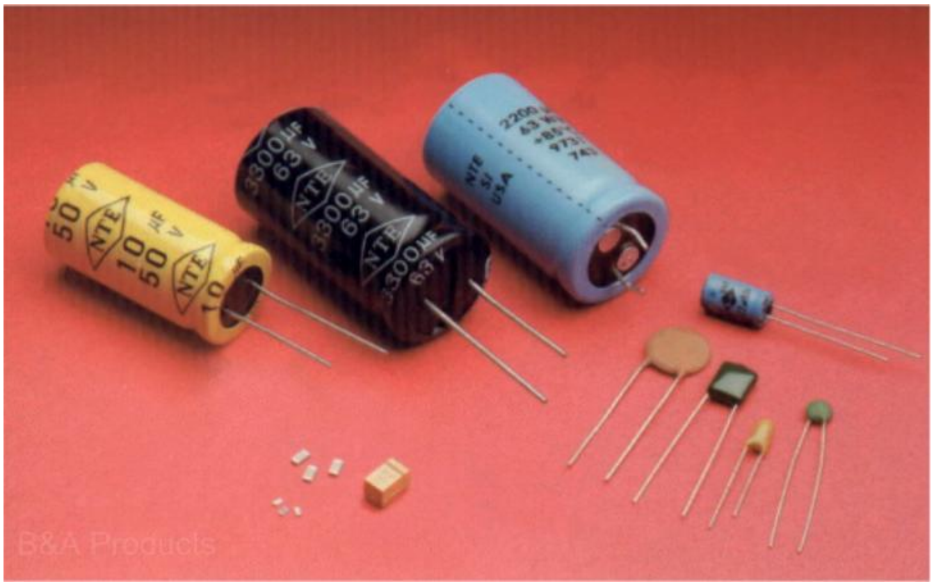
$$C_{total} = 0.667\ \mu F$$

- Thus capacitance is reduced in series



Practical Capacitor Types

- Capacitors cover a wide range of values
- Often identified by the dielectric material in them
- Each dielectric type has different range of values
- Size of C also important – some are very large
- Choose C based on value, size and cost for specific circuit



- Ceramic capacitors (Caps): rods or disk in shape
- Metal foil plates separated by ceramic & ceramic on outside
- Widely used on PC boards
- Covered with ceramic: range 10 pF to 0.1 μF

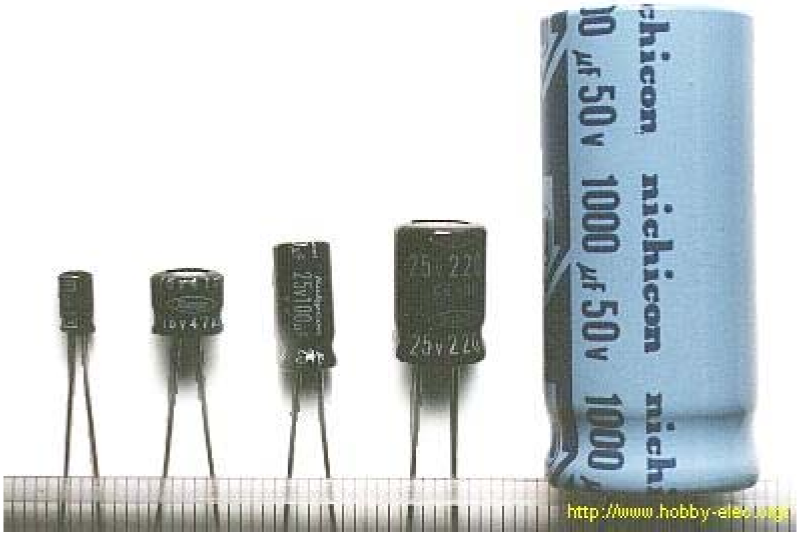
Electrolytic Capacitor

- Paper or Foil capacitors: metal plates separated by paper or plastic
- Quite cheap: range 1 nF to 0.5 μF

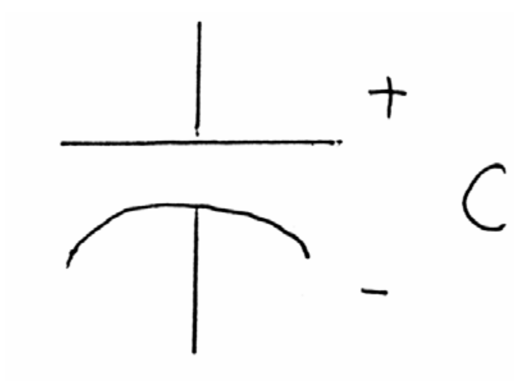
- Mica capacitors: small squares or squarish block
- Metal foil or film separated by mica sheets
- Range: 10 pF to 680 pF

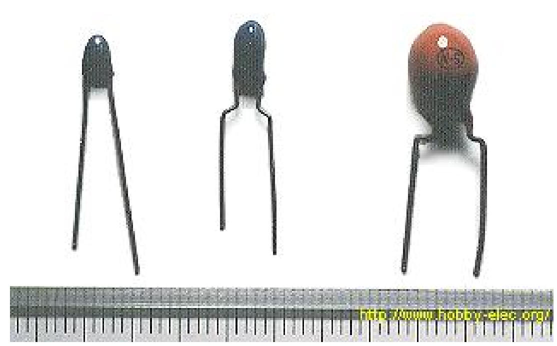
Electrolytic Capacitor

- Electrolytic Capacitor are the largest C type caps
- Are Polarized types – their direction matters
- Has positive and negative marked on capacitor
- Uses a metal (aluminum or tantalum) as anode (electrode)
- Liquid electrolyte as the cathode (other electrode)
- Because liquid is very thin get high E field and thus high C
- However liquid must be orientated in one direction
- If field applied in opposite direction breaks down
- Warning: Explode if charged in wrong direction
- Since thin very high capacitances: 0.1 μF (tantalum) to Farads!
- Tantalum are very small for C value, but expensive



- Electrolytic capacitors are polarized
- Ie. must be placed in given direction to voltage source
- Symbol of Capacitor: Polarized: show + or – on capitor





Wires and Magnetic Fields

- Electric current flow in a wire creates a magnetic field
- Energy is stored in that magnetic field (B)
- Often shown as Field lines
- Circular Field lines around a single wire
- Fields from several wires add together
- Field uses vector addition
- Thus may add, subtract or change direction
- Changes field lines change
- Eg two wires with opposite direction current

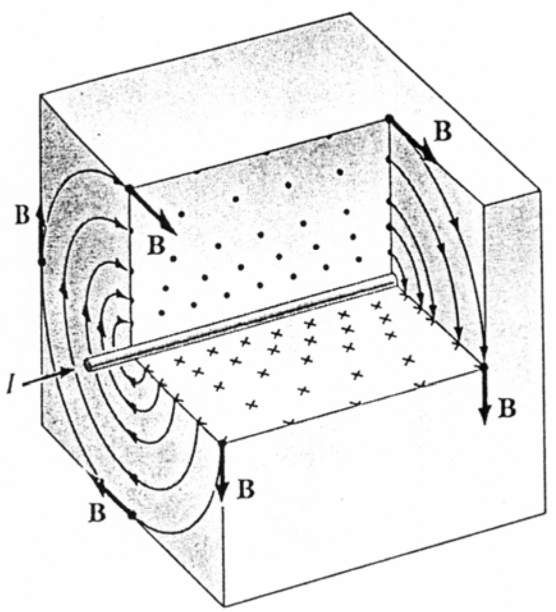


Fig. 32–3. Magnetic field around a long straight conductor.

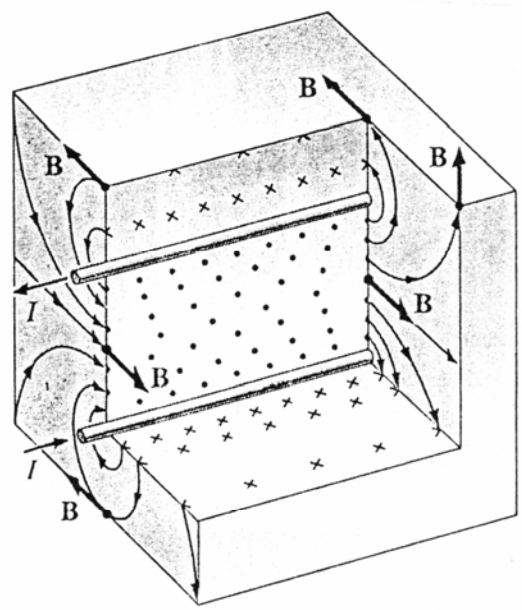


Fig. 32–4. Magnetic field of two long straight conductors carrying currents in opposite directions.

Magnetic Fields, Coils and Inductors

- Circuit elements using magnetic fields called **Inductors**
- Most inductors coils where fields from many wires add up
- Field from a single loop is very symmetric about loop axis
- Since has current I flowing called a current loop
- Combining many loops get a coil
- Fields from a coil are strongest inside the coil, weaker outside
- Easiest to calculate fields at axis of the loop or coil
- Reason same distance from all

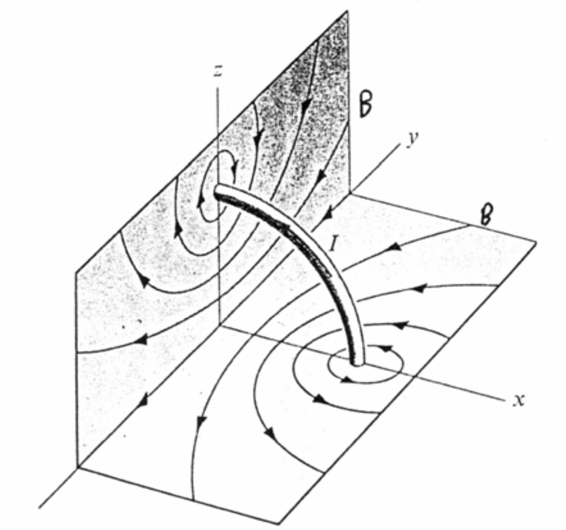
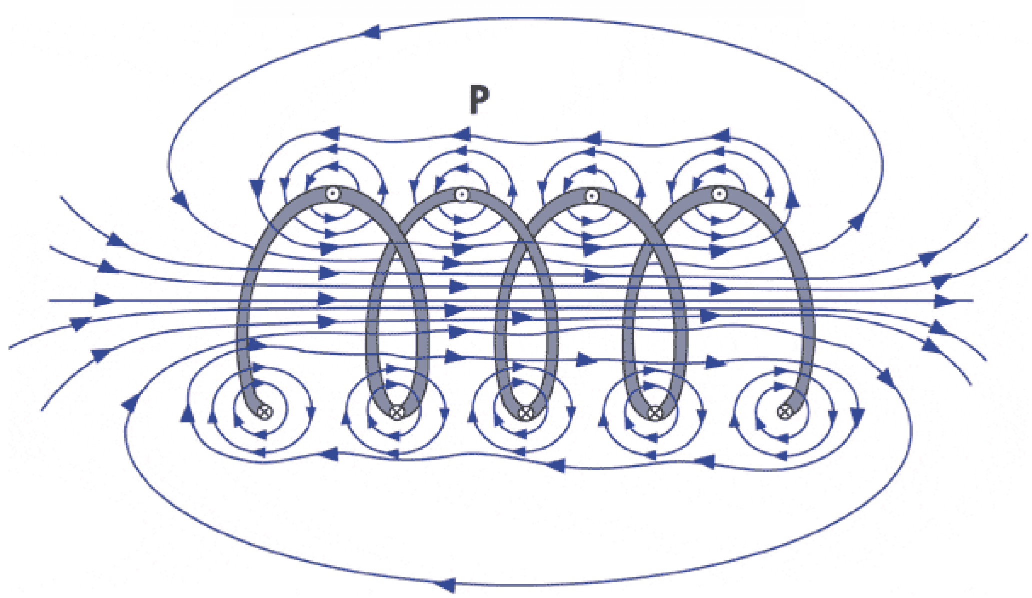


Fig. 32–7. Lines of induction surrounding a circular turn.



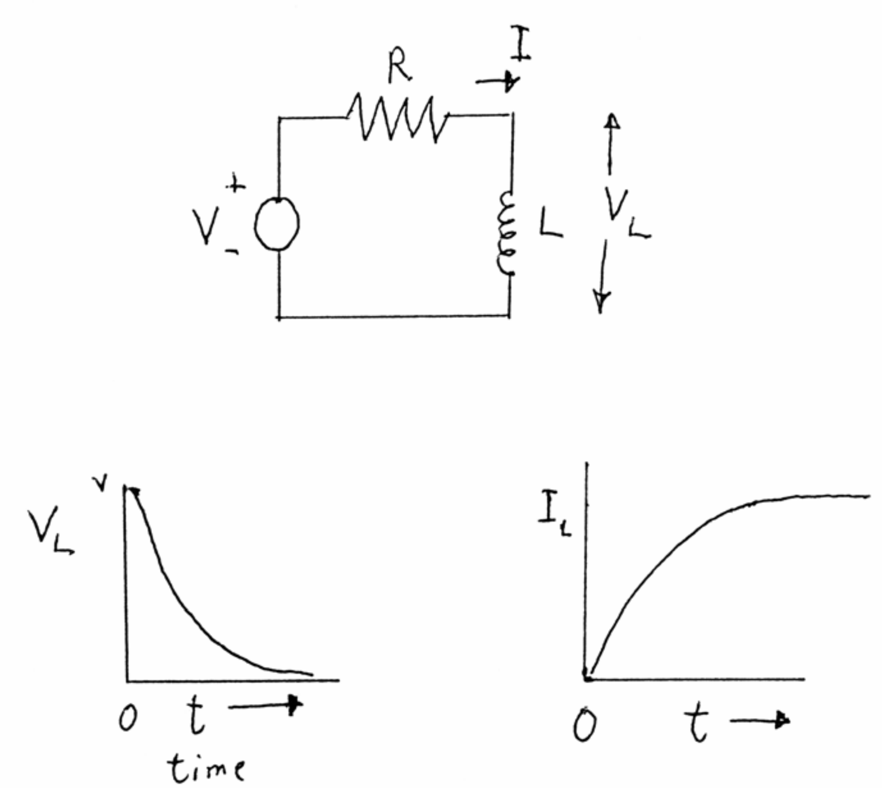
Inductors and Magnetic Fields

- Inductance is the opposition to current changes in a wire
- In circuits often insert Inductors (coils)
- Designate the inductance as L
- Rate their inductance in units of Henries
- L measures energy taken from the current and stored in the field
- Alternately energy is taken from the field and becomes current
- Inductance L relates the opposition to changes in current by:

$$V_L(t) = L\frac{dI}{dT}$$

where L = inductance in Henries (H)

- Typical values millihenries to Henries
- This is the voltage that appears across the inductor
- If no change in current (steady state) no voltage in ideal inductor
- Current level is not important, only the rate of change



Inductors and Current

- Current in inductor is given by

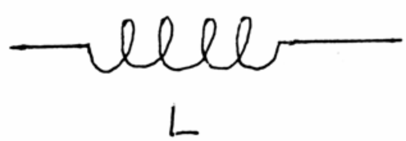
$$I = \int V_L(t)\,dt$$

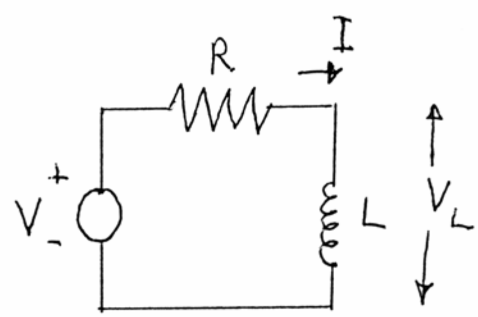
Where

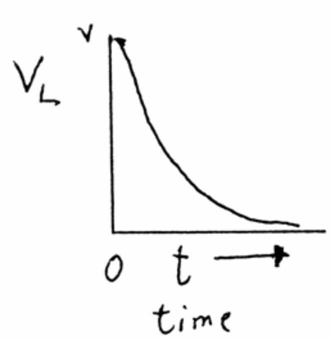
  t = time in seconds

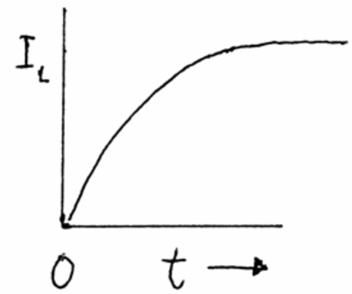
  $V_L(t)$ = instantaneous voltage across the inductor

- This represents the force to change the current in L
- Thus inductor circuits involve Differential Equations
- Will see later, like with C, the special case of AC voltage
- Differential equations can be hidden then
- Thus integrating in time gives:
- Symbol of Inductor is the coil









Energy Storage in Inductors

- Inductor's Energy is stored in the magnetic field
- Thus requires energy to change the field
- Power required to change flow of current I into a Inductor is:

$$p(t) = V(t)I(t) = L\frac{dI}{dt}I(t)$$

- Thus stored energy (or work) in an Inductor by current I is

$$w = L\int_0^T i(t)\frac{di}{dt}dt = \int_0^I i\,di$$

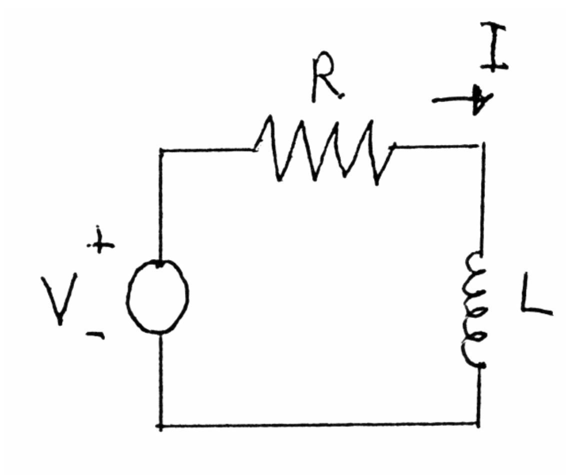
where i(t) is the instantaneous current.

- Thus energy stored in the inductor is

$$w = L\frac{I^2}{2}$$

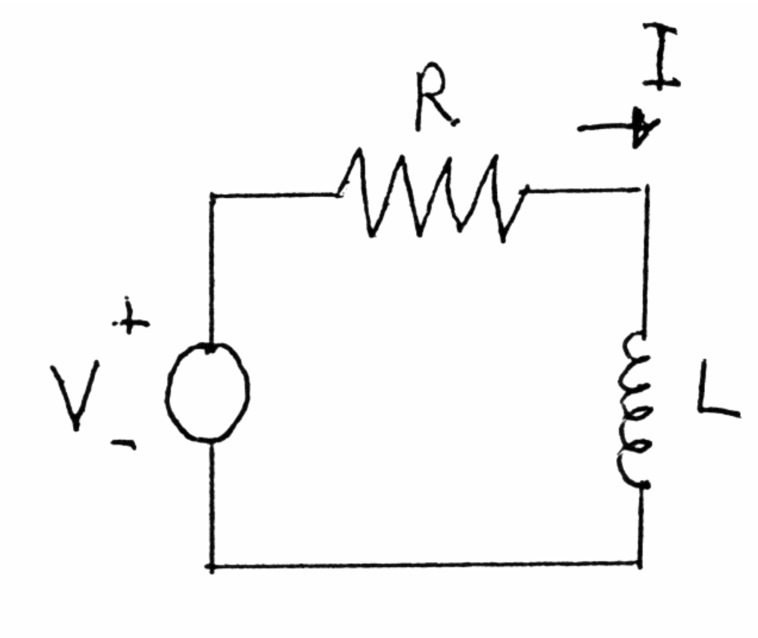
- At any instant the energy stored is

$$w(t) = L\frac{i(t)^2}{2}$$



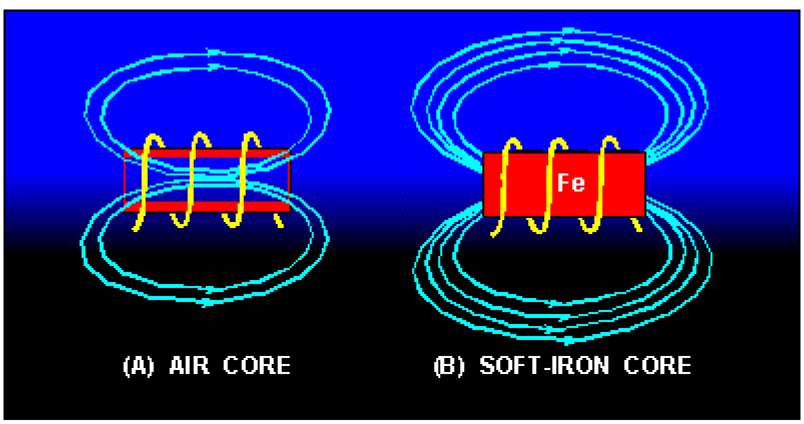
Energy Storage in Inductors

- Capacitors can store energy without a circuit
- However inductors can only store energy in a circuit
- When current is cut the magnetic field falls
- Energy in field tries to use voltage to maintain current
- Inductor acts a short circuit after time for DC Voltage
- Thus for DC eventually voltage across L is zero even if $I \neq 0$
- Inductors are used for energy storage in large system



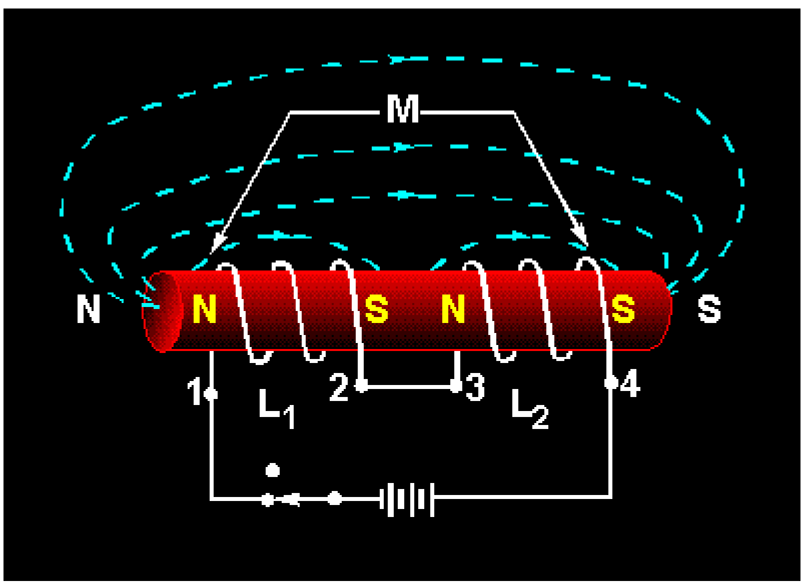
Inductors in Ferric Cores

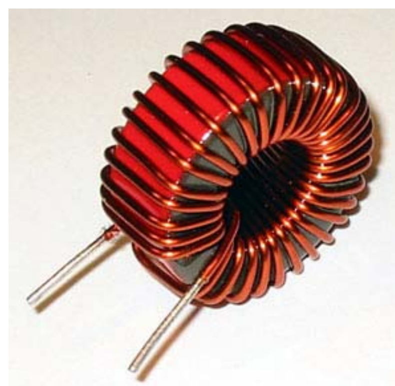
- Simple inductors are “air coils”
- Just wire coils
- Even if wound around typical insulator still that eg plastic
- However if wound on Ferric (Iron like) cores very different
- Ferric material increase the magnetic field from the coil
- Change can be very large (10x or more)
- Reason is coil aligns magnets in Ferric core and B increase
- Effect is to significantly increase L
- However there is a limit to amount of field from core
- Field saturates and L starts decreasing
- Also Ferric core has frequency limit in operation
- Due to hysteresis: where field in Ferric core lags behind changes
- Smallest effect with soft iron cores



Inductors and Mutual Inductance

- Unlike capacitors and inductor can affect its neighbours
- Problem is Magnetic field can extend significant distance
- Even true if both coils wound on same iron rod
- Often call this a solenoid
- This is because fields tend to stay inside rod.
- Inductors in series add to the total inductance
- Effect of one inductor on another called Mutual Inductance (M)
- Can either increase or decrease L
- Calculations become complicated
- Often use inductors spaced so this does not happen
- Or coils where fields are confined to the inductor (donut coils)
- In that case ideally no field outside of inductor and no M
- Field is also stronger than straight typed





Real Inductors

- Ideal inductors would have no resistance
- Real inductors will have many turns of wire
- Especially for air core inductors
- Want many turns of very thin wire
- Thus gives small but finite resistance in the inductor R_L
- Effect becomes important in Resistor Inductor (RL) circuits