ELECTRICAL SCIENCE

UNIT I - 1

INTRODUCTION

Books

1. C.L. Wadhwa
2. ET by H. Cotton
3. Thereja
4. JB Gupta
5. S Parker Smith
6. ~~Hy~~ Hughes Edward
7. Del toro
8. A.E. Fitzgerald
9. DP Kothari
10. Sham Series.

Importance of Circuits

- Circuits / Networks means ~~interconnected~~ set of inter connected components (R, L & C) and Sources.
- This concept is developed in electrical engineering
- Networks exist in other fields of knowledge too
  - In mechanical Engineering : Analogous System
  - In Civil Engineering : Structures, ~~and~~ Rivers etc.
  - Process Engineering
  - Social networking
    - Closed network – Organization
      - [illegible]
      - Friend circle.
    - Open network – Well Connected Person, PRD good
  - Management : Project Engineering : Network of activities
    - ~~Activities~~ : Travelling Salesman Problem
    - : Demand - supply chain.

Rail network
Metro network

Advantages of Electric Network Theory

1. Rich in mathematics,
2. Developed for electric network, but can be applied to other branches of engineering with some modification/s.
3. Like : Laplace Transforms, Fourier Transforms Z - Transforms etc.

Electrical Energy has <u>advantages</u> over other forms of energy

1. Can be transported over long distances with minimum losses and high speed.
2. It can be converted to other forms of energy.

<u>Limitations</u>

Electric energy cannot be stored in large quantities.

It has to be utilized at the moment, it is produced.

<u>Faraday's & Cavendish Instance</u>

<u>Work, energy and Power : you know all these</u>

However,

<u>Average</u>

$$P = \frac{W}{t}$$

Instantaneous

$$p = \frac{dW}{dt}$$

and.

$$W = \int p\,dt$$

<u>Electric Charge</u>

It is difficult to visualize the charge as such. However, it can be best understood by the effects produced by Electric charges.

Such as:

+ve charges
-ve charges
like charges repel
unlike charges attract.
Charge on an electron is -ve 1.602×10^{-19} C

Coulomb's Law

$$F = k \frac{Q_1 Q_2}{d^2}$$

The region where F has its presence is known as field.

Electric field at any point is the force which would be experienced by a unit +ve charge at that point.

Potential Difference / Voltage

It is work done per unit-positive charge in moving a charge between two points.

$$V = \frac{W}{Q} \Rightarrow W = QV$$

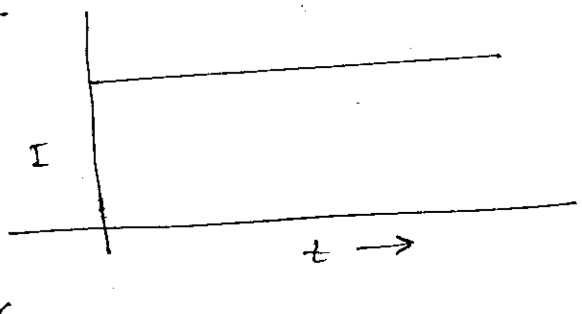
Current

$$I = \frac{Q}{t} \text{ amperes}$$

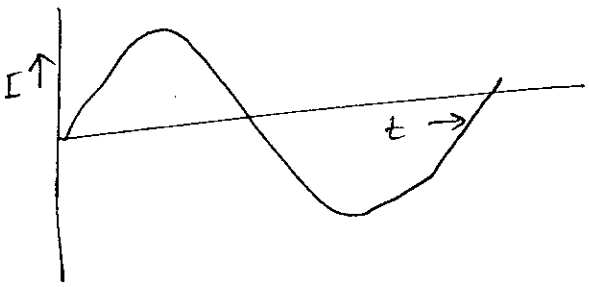
The rate of charge passing a point is current.

$$i = \frac{dq}{dt} \qquad q = \int i \, dt$$

DC



AC



frequency = $\frac{\text{cycles}}{\text{second}}$ = Hz

Magnetic field and electric field exist simultaneously
Electric field is due to static electric charge
Magnetic field is due to motion of electric field.

Power and Energy

$$W = QV$$

$$P = \frac{W}{t} = \frac{QV}{t} = V\left(\frac{Q}{t}\right) = VI \quad \text{watts}$$

$$P = VI \quad \text{Watts.}$$

$$W = VIt \quad \text{Jouls}$$

$$\frac{W}{t} = VI \quad \text{Watts}$$

$$\frac{\text{Joules}}{\text{sec}} = \underline{\text{Watt}}$$

<u>Example</u> A 12-V battery is to be charged by a constant current of 20 A supplied to it for 10 hours of energy supplied to the battery. Seventy percent is converted to chemical energy and stored. The remaining 30 % of energy is converted to heat and lost to the surroundings.

Determine

(a) The cost of charging the battery if electricity cost Rs 5/ kwhs

(b) amount of chemical energy stored.

Soln (a) Total Energy

$$W = VIt$$

$$= 12 \times 20 \times 10 = 2400 \text{ Wh} = 2.400 \text{ kWhr}$$

$$\text{Cost} = W \times \text{rate} = 2.4 \times 5 = \underline{\underline{Rs. 12}}$$

(b) $\eta = 0.7$

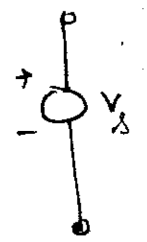
$$W_{chem} = 0.7 \times 2400 = 1680 \text{ Wh} \qquad [\text{W-sec} = \text{J}]$$

$$= 1680 \times \cancel{3600}\ 60 \times 60 = \underline{\underline{6,048,000 \text{ J}}}$$

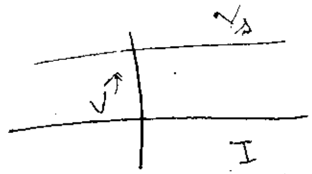
$$= 6048 \text{ kJ}$$

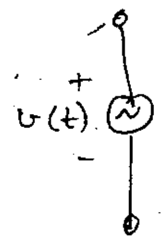
Sources
- Independant
- Dependant
- Ideal
- Practical
- Current
- Voltage

Ideal Voltage Source

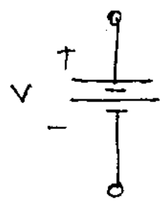


Ideal DC voltage source.
The source has zero internal resistance. Current is determined by the load.

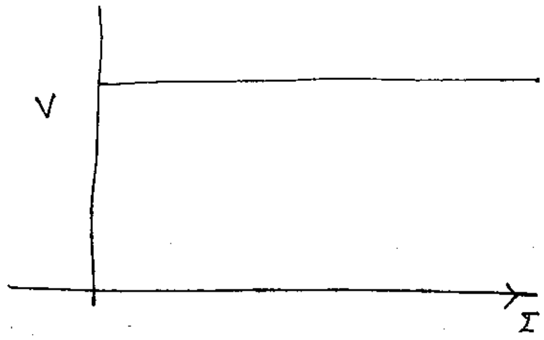




Ideal AC voltage source.



Ideal Battery



1 V dc ~~prod~~ source produces 1 A through 1 Ω resistor

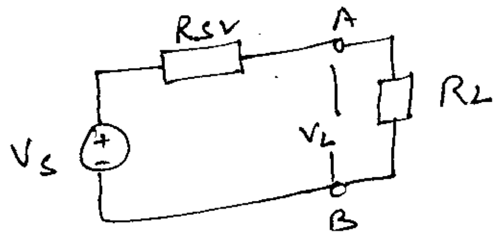
$P = I^2 R = 1^2 . 1 = 1W$

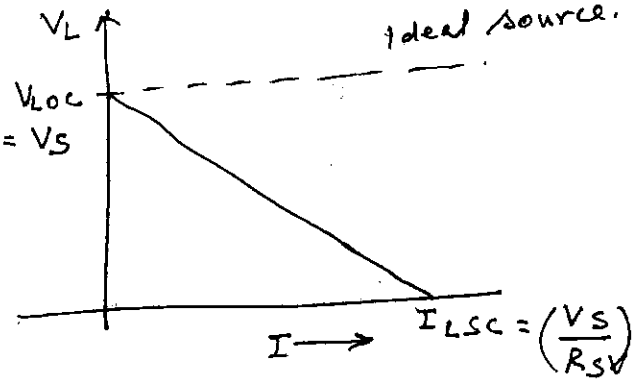
for 1-mΩ resistor $I = 1000$ A

$P = (1000)^2 (1 \times 10^{-3}) = 1000$ W

- This means unlimited power can be drawn from the source. This is not ~~practically~~ possible practically.
- Any source can be considered Ideal for a limited range of operation.
- Example of an automobile starting with head lights ON.

Practical voltage source

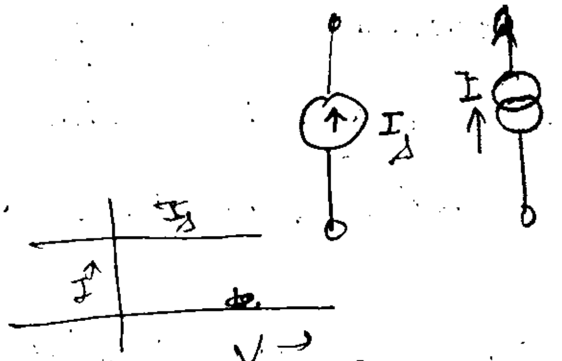




$V_S = \cancel{I} R_L + I R_{SV}$
$= V_L + I R_{SV}$
$V_L = V_S - I R_{SV}$

$I_{LSC} = \frac{V_S}{R_{SV}}$

Ideal Current Source



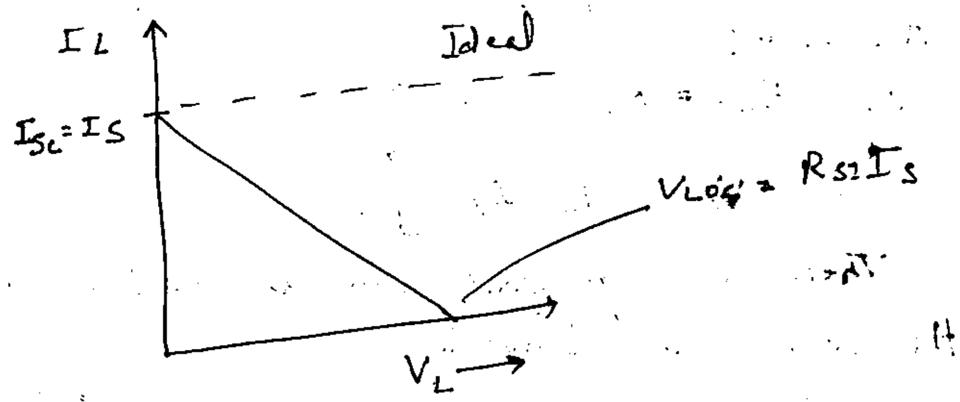
Ideal DC Current Source

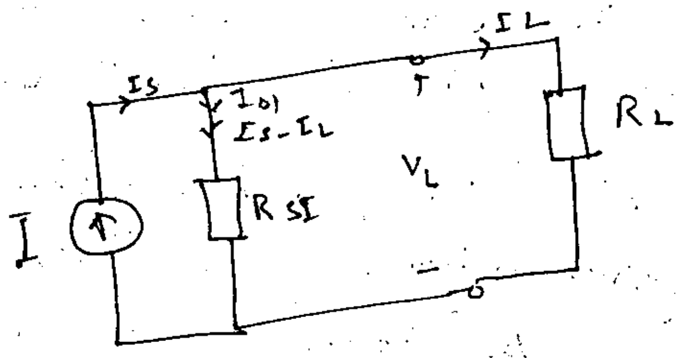
For an independent ideal current source,

- the voltage is determined by load.
- the source has infinite int. resistance.

Ideal AC Current Source

~~Similar Characteristics for Practical~~





$V_L = 0$; S.C. cond

$I_L = I_s$

$I_L = 0$ — O.C.

$V_L = R_{SI} I_s$

$$I_s = I_{SI} + I_L$$
$$= \frac{V_L}{R_{SI}} + I_L$$
$$I_L = I_s - \frac{V_L}{R_{SI}}$$

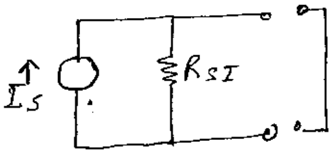
$R_{SI} = \infty$

$I_L = I_s$

Equivalence between Voltage Source and Current Source

- Two sources would be equivalent if they produce identical values of V_L and I_L, when they are connected to the same load R_L, whatever be its value.
- The two equivalent sources should also provide the same V_{oc} and I_{sc}.

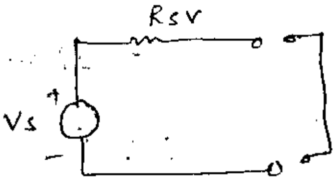
$V_{LOC} \rightarrow$ Load voltage under OC condition



(i)

From (i) & (ii)

$$V_{LOC} = V_s = R_{SI} \; I_s$$



(ii)

$$I_{LSC} = \frac{V_s}{R_{SV}} = I_s$$

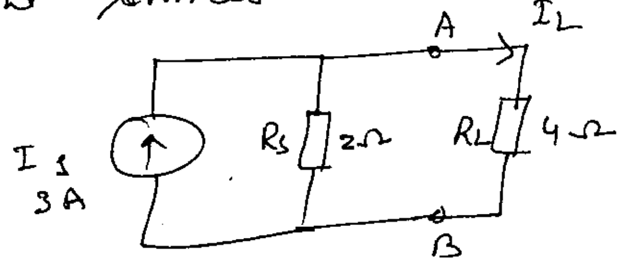
This means

$$\left.\begin{aligned} \therefore \quad R_{SV} = R_{SI} &= R_s \\ V_s &= R_s \; I_s \end{aligned}\right\}$$

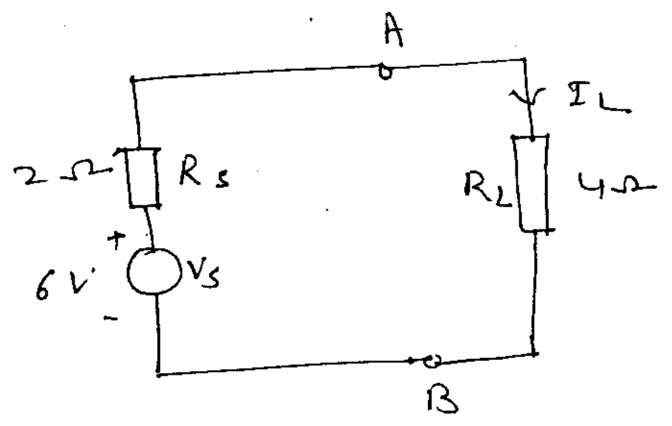
These two equations can be used to determine the equivalent sources.

Caution : The sources determined by this method would be equivalent externally and not internally.

Example Replace the practical current source in the given network by a practical voltage source. Find the power drawn from each of the sources.



Soln.



$R_{sV} = R_{sI} = R_s = 2\,\Omega$

$V_s = R_s I_s = 2 \times 3 = 6\,V$

~~Current~~ Let us check the equivalence

Current through R_L

case I : $I_L = 3 \times \frac{2}{2+4} = 1\,A$

case II : $I_L = \frac{6}{2+4} = 1A$

Voltage Across R_L

case I : $V_L = 1 \times 4 = 4\,V$

case II : $V_L = 6 \times \frac{4}{6} = 4\,V$

This shows that sources are equivalent externally

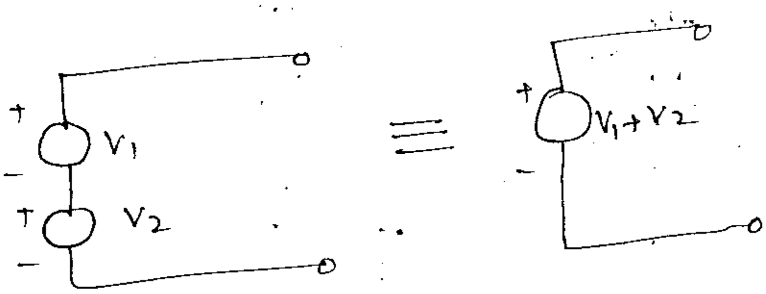
Next, let ~~ea~~ us calculate power drawn

case I : $P_s = I_s^2 R = 3^2 \times \frac{2 \times 4}{2+4} = 12\,W$

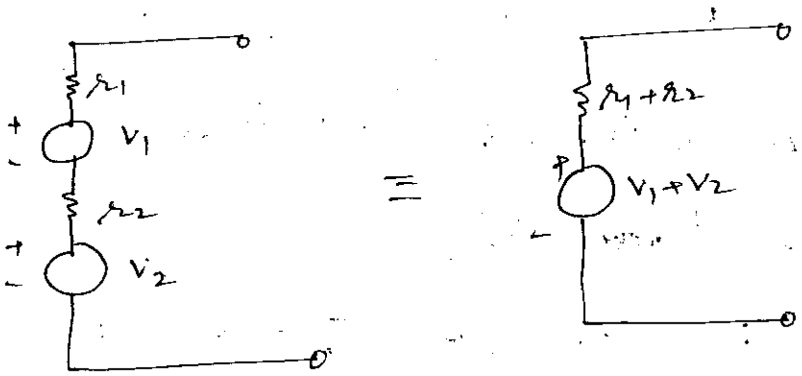
case II $P_s = \frac{V_s^2}{R} = \frac{6^2}{6} = 6\,W$

This is different means power drawn from sources are different, but power delivered is same in both the cases.

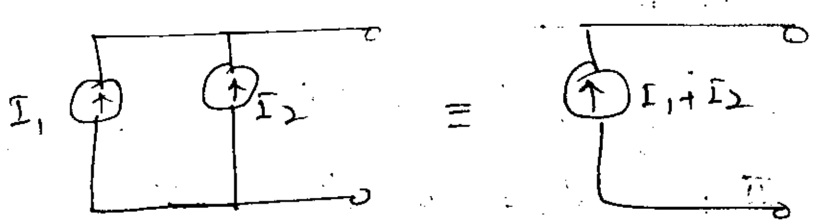
Ideal Voltage Sources Connected in Series



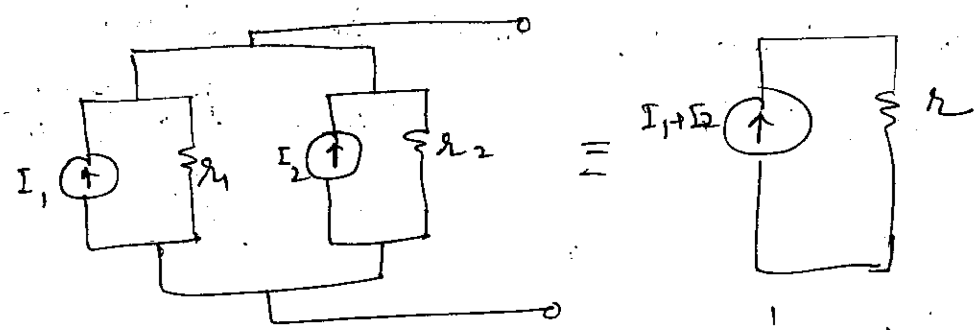
Practical Voltage Sources Connected in Series



Ideal Current Sources Connected in Parallel

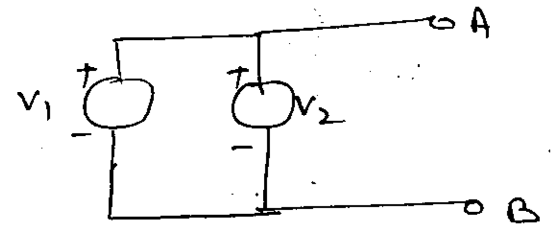


Practical Current Sources Connected in Parallel



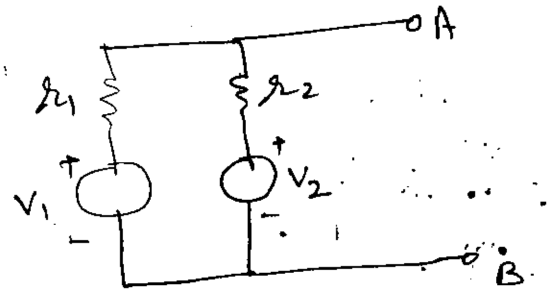
$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2}$$

Ideal Voltage Sources in Parallel



what voltage should appear across terminals A B V_1 or V_2 ? This is a contradiction. So is not possible practical. Therefore, such connection should not be assumed

Practical Voltage Sources in parallel



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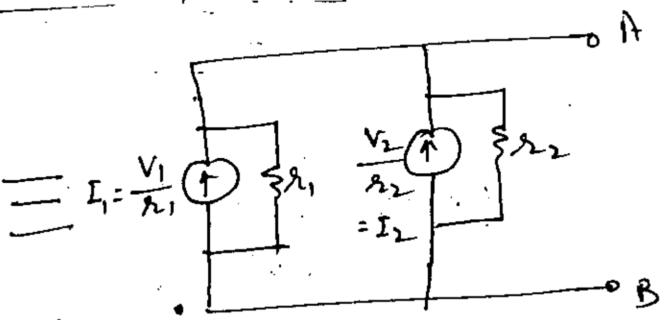

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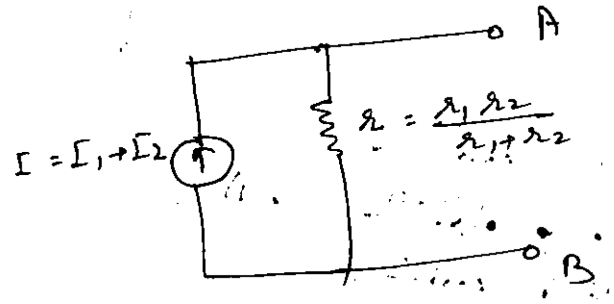
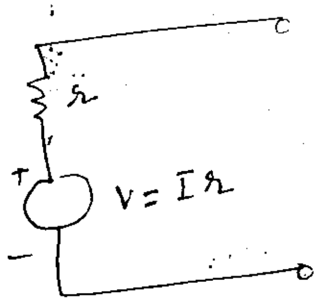
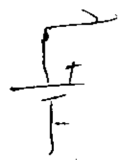
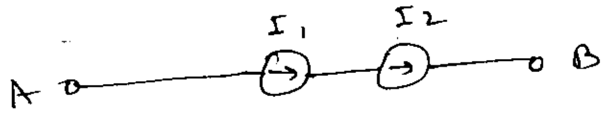


$\equiv$



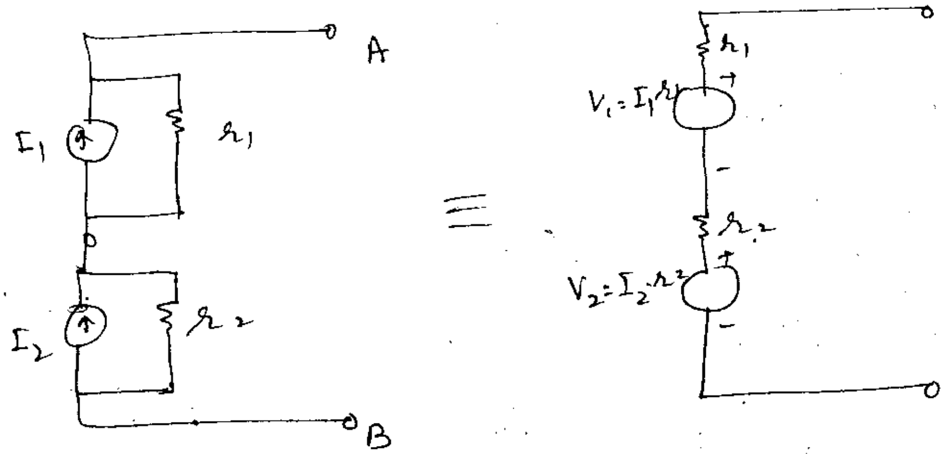


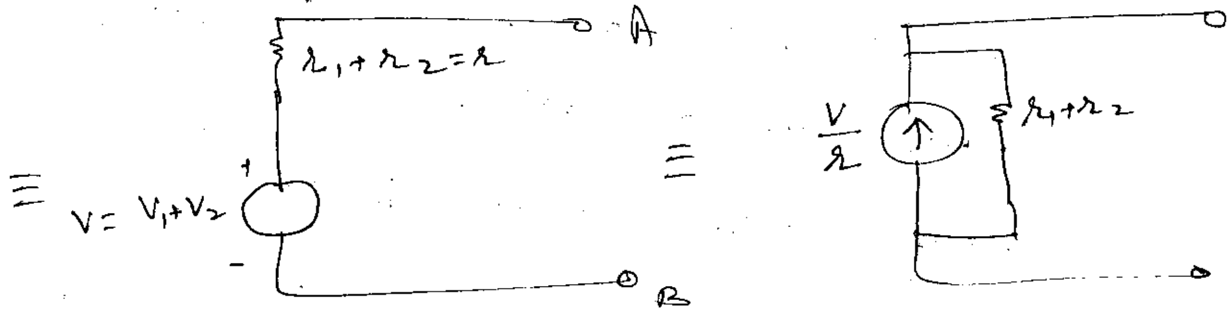
Ideal Current Sources in Series



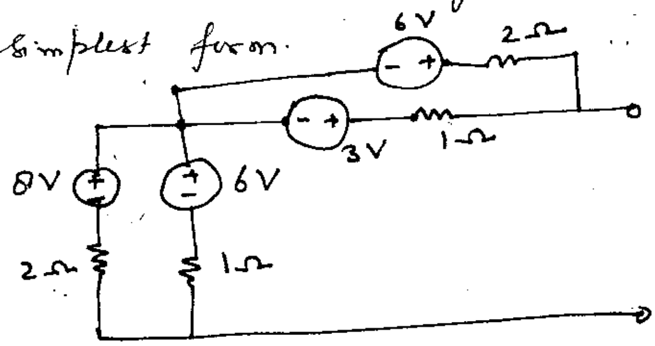
Again a contradiction, so this type of connection should not be assumed.

Practical Current Sources Connected in Series

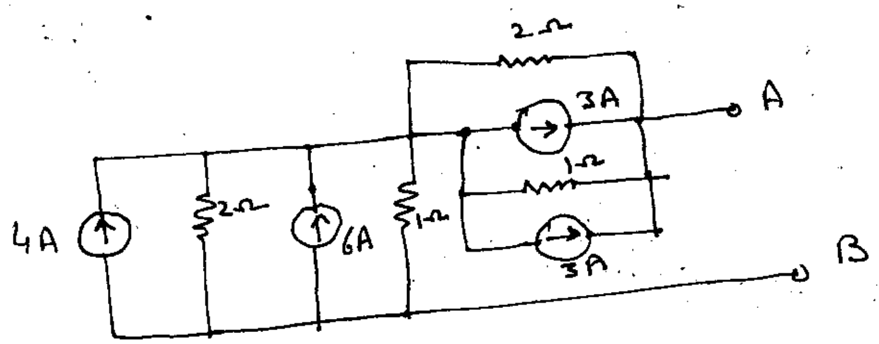




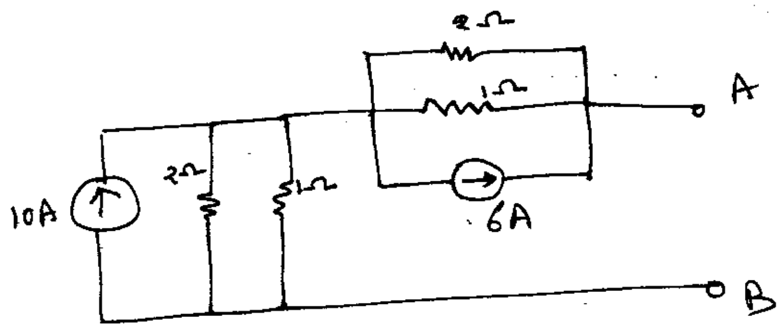
Example : Reduce the given network to the simplest form.



Soln



⇒



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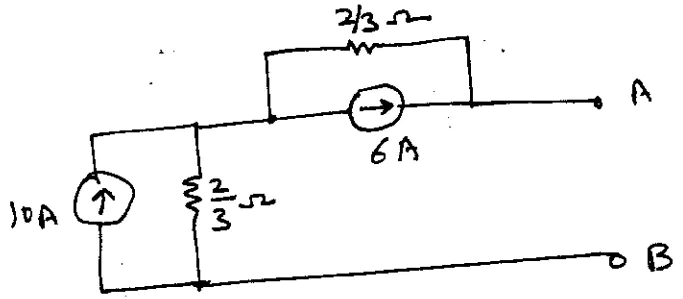

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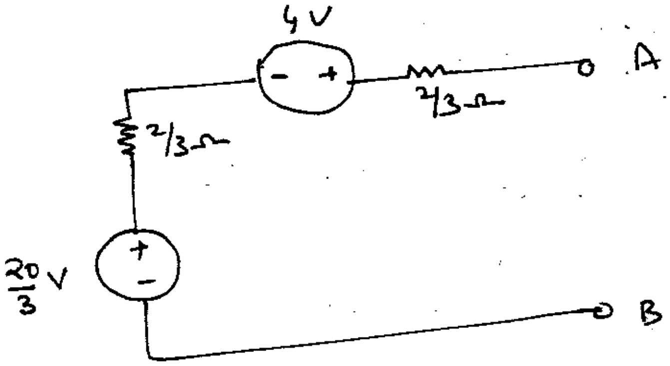

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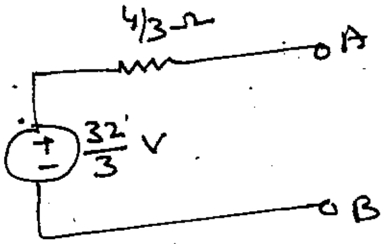


7/8/13

Example: In the figure given

(a) If $R_L = 80\Omega$ find i_L

(b) Transform the practical current source into a practical voltage source and find i_L if $R_L = 80\Omega$ again

(c) Find the power drawn from the ideal source in each case.

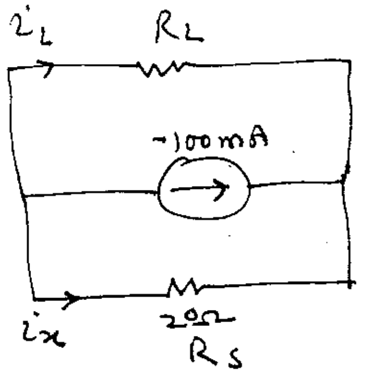


Fig A

Soln.

(a) $$i_L = 100 \times \frac{20}{20+80} = \underline{20 \text{ mA}}$$

(b)

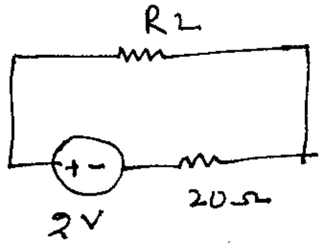
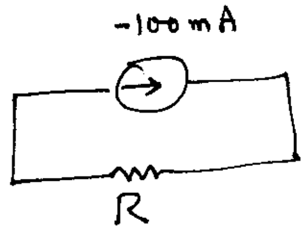


Fig B

$$i_L = \frac{2}{20+80} = \underline{20 \text{ mA}}$$

(c) for fig A

=



$$R = \frac{20 \times 80}{20+80} = 16\,\Omega$$

$$\text{Power drawn} = I^2R = (0.1)^2 \times 16 = .16 \text{ W} = \underline{160 \text{ mW}}$$

For fig B

$$P = \frac{V^2}{R} = \frac{2^2}{100} = \frac{4}{100} = \underline{40 \text{ mW}}$$

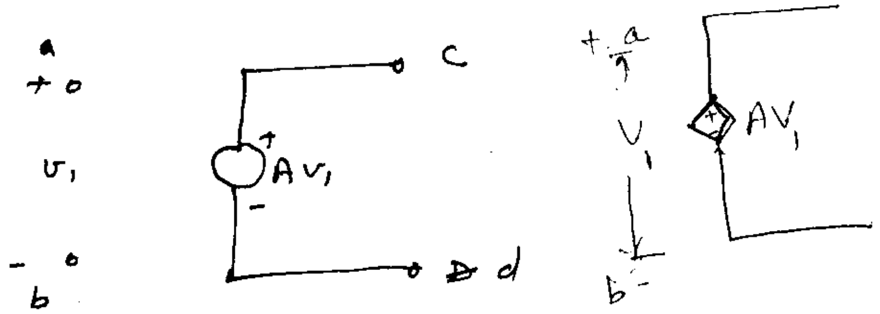
Note: Here the powers are different. This again demonstrates the fact that the source transformation ~~are~~ is equivalent as long as we consider the outside circuit, but for the inside of practical sources the situation is different.

Dependent Sources

There are 4 types of dependent sources

1. Voltage controlled voltage source
2. Current " "
3. Voltage " Current " e.g. op. Amp.
4. Current " " "

1.



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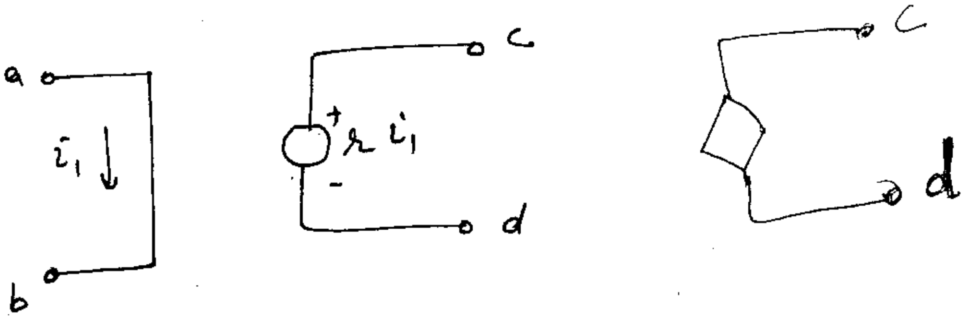

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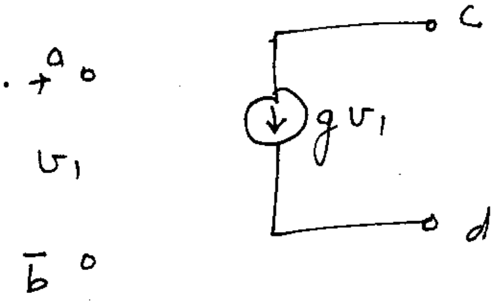

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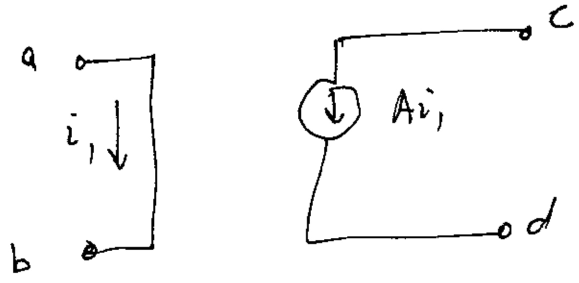


Important features of Dependent Sources

1. They behave similar to independent sources
2. The source value depends upon the controlling parameter.
3. Independent sources can be represented by two terminals
4. Dependent sources need 4 terminals for representation.

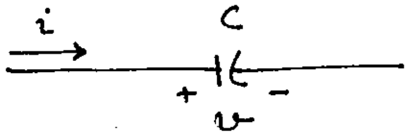
PASSIVE CIRCUIT COMPONENTS

These are R, L and C

The Capacitance Parameter

capacitor is a component
capacitance is a parameter } It has two large metal surfaces seperated by comparatively smaller distance.

Circuit Point of View It stores energy in an electric field.



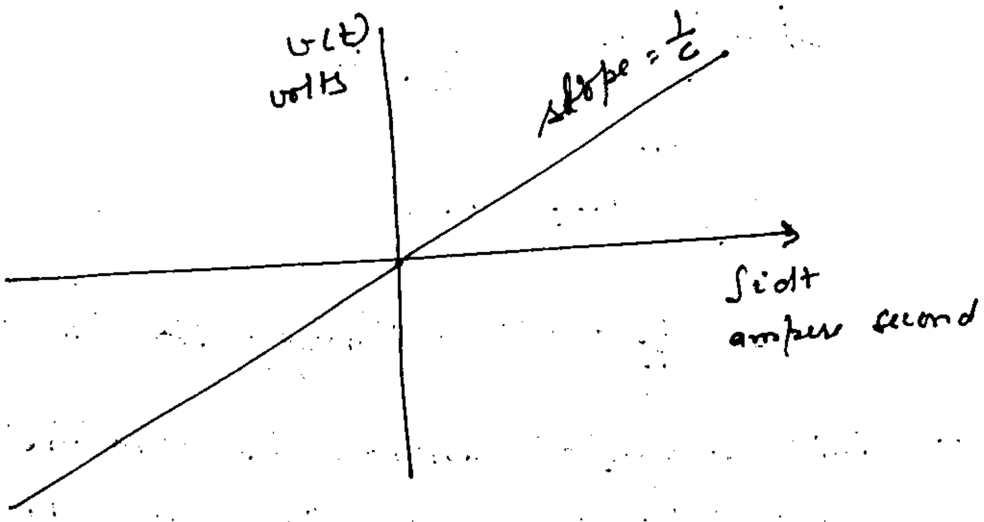
$$i = C\frac{dv}{dt} \Rightarrow C = \frac{i}{dv/dt}$$ ampere-second per volt (farad)

$$\Rightarrow dv = \frac{1}{C}\, i\, dt$$

$$\int_{v(0)}^{v(t)} dv = \frac{1}{C}\int_0^t i\, dt$$

$$v(t) = \frac{1}{C}\int_0^t i\, dt + v(0)$$

$v(0)$ means the initial condition



— The voltage across the capacitor cannot change instantaneously because of $\int$ sign present.

✡ This is clear from eq. (1) & eq. (2)

from. $i = c\frac{dv}{dt}$ — (1)

— If the voltage across the capacitor doesn't change; i.e. $\frac{dv}{dt} = 0$; ~~i = 0~~ then $i = 0$.

— Further, if voltage across capacitor changes instantaneously i.e. $\frac{dv}{dt} = \infty$, then $i = \infty$ which is impossible and therefore v can not change instantaneously.

Energy View Point of Capacitor

Let
1. voltage across the capacitor is zero initially i.e. $v = 0$ at $t = 0$
2. current i is allowed to flow through the capacitor. for a time t.

Then Energy delivered to capacitor = energy stored in capacitor

$$W = \int_0^t v\,i\,dt$$

we know $i = c\frac{dv}{dt}$

Then

$$W = \int_0^t v \left(C \frac{dv}{dt} \right) dt$$

$$= \int_0^v vC \, dv$$

$$= \frac{1}{2} C v^2 = \text{Energy stored in capacitor}$$

- This energy is utilized for establishing an electric field in the region between plates of the capacitor.
- This energy would be released by the capacitor if the voltage of the source decreases below the voltage to which capacitor has been charged. If voltage is constant, no current flow, but the energy will be stored.

Also, $C = \dfrac{2W}{v^2}$

<u>Geometric View Point of Capacitor</u>

Let us consider a parallel plate capacitor

- It has two flat parallel plates of surface area A, seperated by a distance d.
- ϵ is the permittivity of the material (medium) between the plates.

Then

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

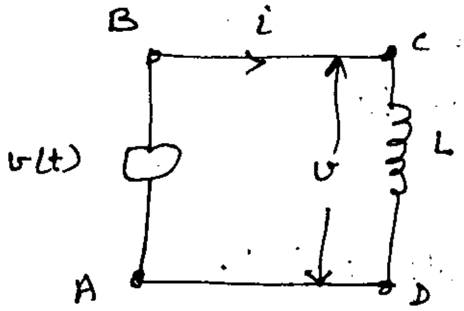
The Inductance Parameter

Inductor is a component

Inductance is a parameter

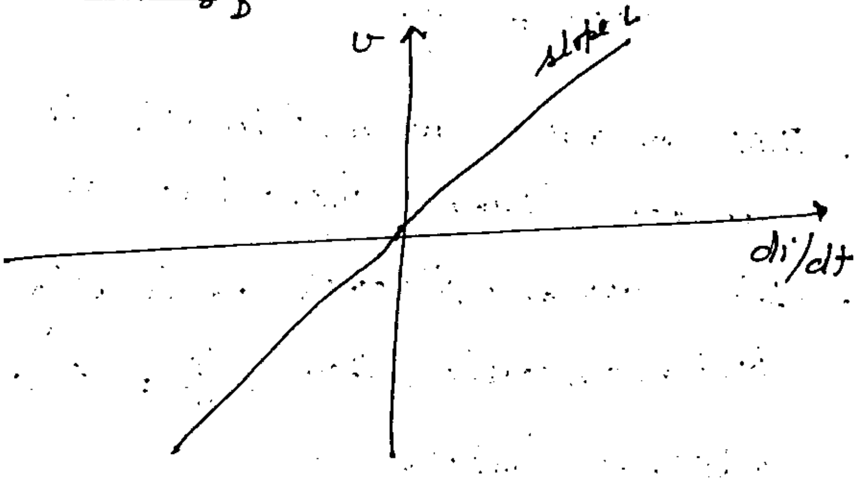
- Inductor is a coil wound over a core
- It stores energy in a magnetic field.
- It plays a role only when there is a change in current flowing through the inductor
- Also, current through an inductor can not change instantaneously.
- If a constant current flows through an inductor ($\frac{di}{dt} = 0$), it behaves as a short circuit.

Circuit Point of View of an Inductor



$$v = L \frac{di}{dt}$$

L = Inductance



- Ideally an inductor has no resistance.
- But, practically, it is made up of a coil of conducting material and has to have a resistance.

$$v = L\frac{di}{dt}$$

$$\Rightarrow \quad L = \frac{v}{(di/dt)} = \frac{\text{Volt - second}}{\text{Ampere}} = \text{Henry}$$

- If L is independent of i, it is said to be linear.
- To increase the value of L the core is made of iron, then inductor doesn't remain linear. i.e. it is non-linear.

$$v = L\frac{di}{dt}$$

$$\Rightarrow \quad di = \frac{1}{L} v\, dt$$

$$\int_{i(0)}^{i(t)} di = \frac{1}{L}\int_0^t v\, dt$$

$$i(t) = \frac{1}{L}\int_0^t v\, dt + i(0)$$

- This means current i through the inductor can not change instantaneously.
- If current i through an inductor changes instantaneously, then $\frac{di}{dt} = \infty$, then $v = \infty$ which is impossible.
- Further if current i doesn't change i.e. $\frac{di}{dt} = 0$ then $v = 0$.

Energy Point of View of an Inductor

Let

1. the initial current is zero.
2. the current rises from 0 to i in the time interval from 0 to t.

- The energy received by the inductor

$$= W = \int_0^t v i \, dt$$

$$= \int_0^t \left(L \frac{di}{dt}\right) i \, dt$$

$$= \int_0^t L i \, di = \frac{1}{2} L i^2 .$$

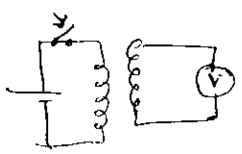
[R has been assumed to be zero]

- This energy is neither spent nor dissipated, it remains stored in the magnetic field of the inductor.
- This energy can be retrieved by reducing the current through the inductor.

$$\boxed{L = \frac{2W}{i^2}}$$

- As $v = L\frac{di}{dt}$, so potential difference across an inductor (v) occurs only as long as $\frac{di}{dt}$ is finite and $\neq 0$. If i is constant $\frac{di}{dt} = 0$ and so $v = 0$.

Example:



- energy stored in an inductor remains constant as long as the current i is constant.
- Any attempt to change the energy stored (W) is ~~of~~ opposed by the initial energy stored.
- This is inertia property of an inductor.

For this reason a mass in Mech. system $\equiv$ inductor in electrical systems.

Geometric View Point of Inductor

v = voltage induced in inductor

i = current flowing in "

ϕ = flux produced

N = Number of turns

Then Faraday's Law gives

$$v = N\frac{d\phi}{dt} = N\frac{d\phi}{di}\frac{di}{dt}$$

Also we know $v = \frac{L\,di}{dt}$

$$\therefore \quad L = N\frac{d\phi}{di} \qquad [\text{for any inductor}]$$

For linear inductor we can write

$$L = N\frac{\phi}{i}$$

~~$\phi =$~~

We know (or let us define)

$$\phi = \frac{mmf}{\text{magnetic reluctance}} = \frac{Ni}{S}$$

Let us consider a linear inductor of

N turns
iron core of length l
cross-sectional area A

Then

Magnetic Reluctance

$$S = \frac{l}{\mu A} \qquad R = \rho \frac{l}{A} = \frac{1}{\sigma} \frac{l}{A}$$

μ = permeability of medium.

Starting from

$$L = N \frac{\phi}{i} \quad \text{and} \quad \phi = \frac{Ni}{S}$$

$$L = N \frac{Ni}{iS} = \frac{N^2}{S}$$

Put $S = \frac{l}{\mu A}$

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

This gives the Geometric view point of an inductor.

PTO

The Resistance Parameter

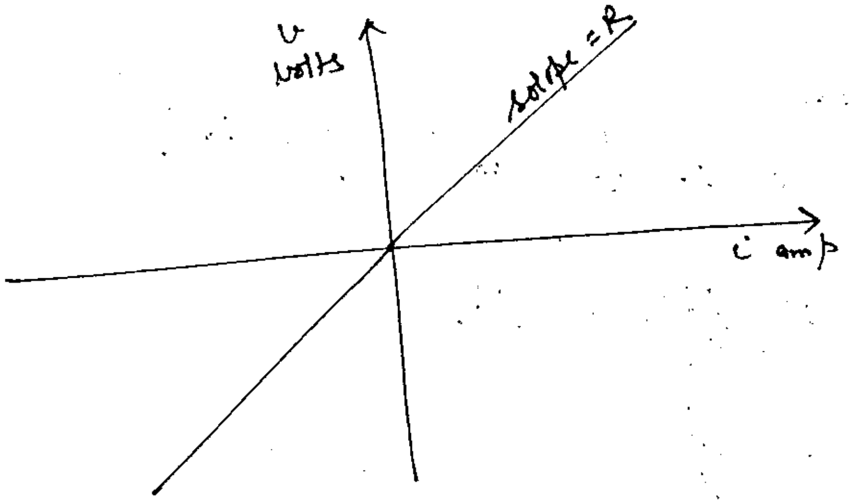
Resistor — component / circuit element

Resistance — Parameter

Resistance is the property of a circuit element which opposes the flow of current through it

Circuit Point of View

$$R = \frac{v}{i} \Rightarrow v = iR$$



[What is the resistance of a 100W 230V bulb when measured with the help of a multimeter]

R depends on Temperature

$$R_2 = R_1 \left[1 + \alpha_1 (T_2 - T_1)\right]$$

α_1 = temperature coefficient of resistance at T_1

Energy Point of View

Power delivered to resistor is converted into heat.

$$p = vi \quad \& \quad \cancel{v = \frac{R}{i}} \quad R = \frac{v}{i} \ ; \ v = iR$$

$$p = (iR)\, i = i^2 R$$

[What is R of a 100W 230 bulb when in use].

$$w = i^2 R\, t$$

<u>Example</u> A $100\,\Omega$ resistor is needed in an electric circuit to carry a current of 0.3 A. The following resistors are available form stock

$100\,\Omega$ 5W ; $100\,\Omega$ 10W ; $100\,\Omega$, 20W

Which resistor would you specify

<u>Soln.</u>

$$p = i^2 R = (0.3)^2 100 = \underline{9\,W}$$

Hence a $100\,\Omega$, 10 W resistor would be specified

<u>Geometric View Point</u>

$$R = \rho \frac{L}{A} \quad \Omega \qquad \rho = \frac{RA}{L} = \underline{\Omega\text{-}m}$$

ρ = Resistivity of the material

L = length of Conductor, m

A = crossesection area, m^2

conductance $G = \frac{1}{R}$

conductivity $\sigma = \frac{1}{\rho}$

<u>Example</u>: calculate the value of capacitance parameter in each of the following cases:

(i) two flat parallel plates are seperated by 0.1 mm thick layer of mica having a relative permittivity of 10 and a total area of $0.113 m^2$

(ii) A voltage of 100 V yields an energy storage of 0.05 J in an electric field

(iii) A voltage increases from 0 to 100 V in 0.1 sec. causing a current flow of 5 mA.

Soln: (i) $$C = \epsilon \frac{A}{d} = \epsilon_r \epsilon_0 \frac{A}{d}$$

$$\epsilon_r = 10 \qquad \epsilon_0 = 8.854 \times 10^{-12}$$

$$A = 0.113 m^2 \qquad d = 0.1 \times 10^{-3} m$$

$$C = \frac{10 \times 8.854 \times 10^{-12} \times 0.113}{0.1 \times 10^{-3}} = \underline{0.1 \mu F}$$

(ii) $$C = \frac{2W}{V^2} = \frac{2 \times 0.05}{(100)^2} = \underline{10 \mu F}$$

(iii) $$C = \frac{i}{dv/dt} = \frac{5 \times 10^{-3}}{100/0.1} = \underline{5 \mu F}$$

Example: Find the inductance of the coil in each of the following cases

(i) A current of 0.2 A yields an energy storage of 0.2 J in a magnetic field.

(ii) A current increases linearly from 0 to 0.1 A in 0.2 sec. producing a voltage of 10 V

(iii) A current of 0.1 A increases at the rate of 0.5 A/sec. producing a power of 2.5 W

Soln: (i) $L = \frac{2W}{i^2} = \frac{2 \times 0.2}{0.2 \times 0.2} = \underline{10\ H}$

(ii) $L = \frac{v}{di/dt} = \frac{10}{0.1/0.2} = \underline{20\ H}$

(iii) $p = i L \frac{di}{dt}$

$L = \frac{p}{i\ di/dt} = \frac{2.5}{0.1 \times 0.5} = \underline{50\ H}$