



**ACE**  
Engineering Academy  
(Leading institute for ESE/GATE/PSUs)

# **ESE – 2019 MAINS OFFLINE TEST SERIES**



**ELECTRONICS & TELECOMMUNICATION  
ENGINEERING (E&T)**

## **TEST – 7 SOLUTIONS**

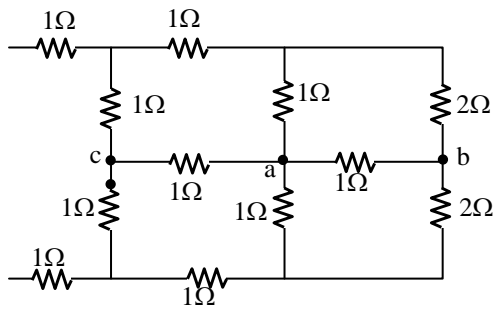
All Queries related to **ESE – 2019 MAINS Test Series** Solutions are to be sent to the following email address  
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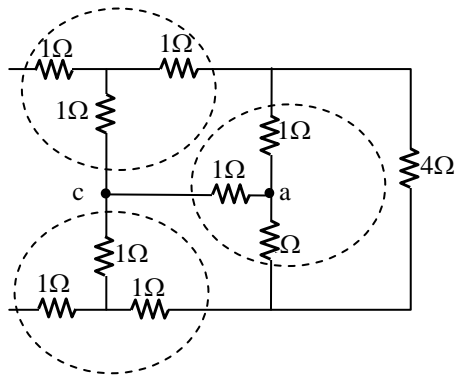
01. (a)

Sol:

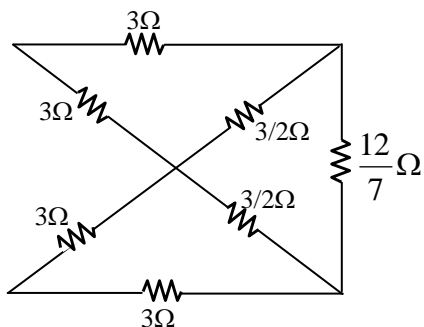
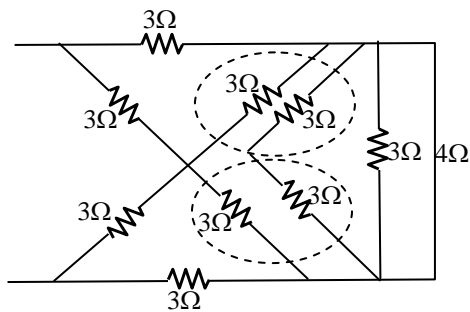
The given circuit can be redrawn as

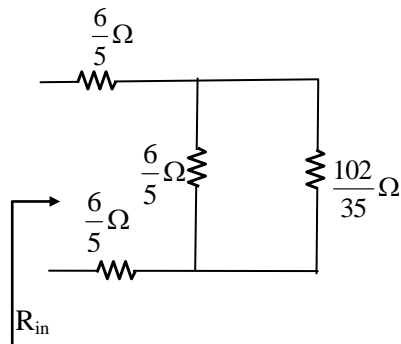
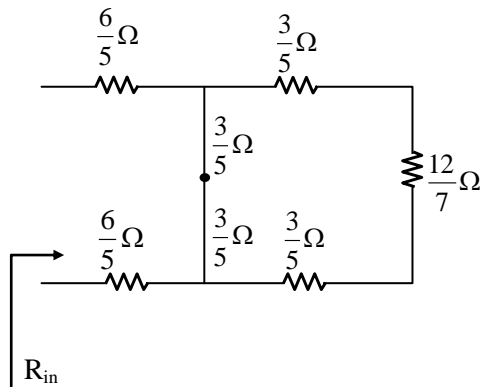


The  $1\Omega$  resistor between nodes 'a' and 'b' can be neglected by bridge balance.



By Y -  $\Delta$  transformation





$$R_{in} = \frac{6}{5} + \left( \frac{6}{5} // \frac{102}{35} \right) + \frac{6}{5}$$

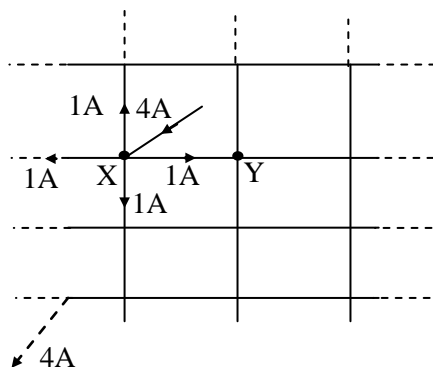
$$R_{in} = \frac{13}{4} \Omega$$

**01. (b)**

**Sol:**

**Step -1**

Inject a current of +4 at 'X' and collect at " $\infty$ "



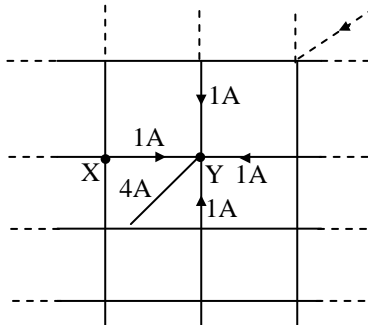
$$V'_{xy} = 1(1\Omega) = 1V,$$

$$I'_{xy} = 1A$$



**Step2:**

Inject a current of 4A at ' $\infty$ ' and collect at 'Y'



$$V_{XY}'' = 1(1\Omega) = 1V,$$

$$I_{XY}'' = 1A$$

By superposition principle,

$$I_{XY} = 1 + 1 = 2A$$

**01. (c)**

**Sol:**

**(i) Noise margin:**

It is a measure of the circuits immunity to noise. The high level and low level noise margins are represented by  $V_{NH}$  and  $V_{NL}$  respectively.

$$V_{NH} = V_{OH(min)} - V_{IH(min)} = V_{DD} - V_{IH}$$

$$V_{NL} = V_{IL(max)} - V_{OL(max)}$$

→ Desire large  $V_{NH}$  and  $V_{NL}$  for best noise immunity i.e., noise margin will increases with increase in supply voltage ( $V_{DD}$ ). This is because the width of the regions which are considered logical high or logical low increases with increases in  $V_{DD}$ .

**(ii) Power dissipation:**

Power dissipation in CMOS circuits is frequency dependent. It is extreme low under static (dc) conditions and increases as the frequency increases. Total dynamic power dissipation of a CMOS circuit is:

$$P_D = P_1 + P_L = C_{PD} \cdot V_{DD}^2 \cdot f + C_L \cdot V_{DD}^2 \cdot f = (C_{PD} + C_L) V_{DD}^2 \cdot f$$

Where,

$P_1$  = internal power dissipation of the gate.

$P_L$  = External power dissipation due to capacitive load.

$C_{PD}$  = Internal power dissipation capacitance

$C_L$  = External load dissipation capacitance

$V_{DD}$  = supply voltage

$f$  = Transition frequency of the output signal

i.e., power dissipation increases as the supply voltage ( $V_{DD}$ ) increases i.e., as the input and output capacitances will now need to be charged to a higher level.

**(iii) Switching speed:**

For a given voltage increase until constant current region. The more current available to charge the capacitance in the device, thus faster switching.

As increase the gate voltage for a given  $V_{ds}$ , the current increase, which charges a given amount of capacitance the faster.

∴ Switching speed will increase with the increase in supply voltage as the delay time is inversely proportional to  $V_{DD}$ .

**01. (d)****Sol:****(i) Dielectric constant ( $\epsilon_r$ )**

The dielectric characteristic of a material are determined by the dielectric constant or relative permittivity  $\epsilon_r$  of that material. Dielectric constant is the ratio between the permittivity of the medium and the permittivity of free space.

$$\text{i.e., } \epsilon_r = \frac{\epsilon}{\epsilon_0}$$

Since it is a ratio of same quantity,  $\epsilon_r$  has no unit. It is a measure of polarization in the dielectric material.

**(ii) Electric polarization**

Let us consider an atom placed inside an electric field. The centre of positive charge is displaced along the applied field direction while the centre of negative charge is displaced in the opposite direction. Thus a dipole is produced. When a dielectric material is placed inside an electric field such dipoles are created in all the atoms inside. This process of producing electric dipoles which are oriented along the field direction is called polarization in dielectrics.

**(iii) Polarisability ( $\alpha$ )**

When the strength of the electric field  $E$  is increased the strength of the induced dipole  $\mu$  also increases. Thus the induced dipole moment is proportional to the intensity of the electric field.

$$\text{i.e., } \mu = \alpha E$$

Where  $\alpha$ , the constant of proportionality is called polarisability. It can be defined as induced dipole moment per unit electric field.

**(iv) Polarization vector ( $\vec{P}$ )**

The dipole moment per unit volume of the dielectric material is called polarization vector  $\vec{P}$ . If  $\vec{\mu}$  is the average dipole moment per molecule and  $N$  is the number of molecules per unit volume the polarization vector

$$\vec{P} = N\vec{\mu}$$

The dipole moment per unit volume of the solid is the sum of all the individual dipole moments within that volume and is called the polarization  $\vec{P}$  of the solid.

**(v) Electric susceptibility ( $\chi_e$ )**

The polarization vector  $\vec{P}$  is proportional to the total electric flux density  $E$  and is in the same direction of  $E$ . Therefore the polarization vector can be written as

$$P = \epsilon_0 \chi_e E$$

Where the constant  $\chi_e$  is the electric susceptibility

$$\text{Therefore } \chi_e = \frac{P}{\epsilon_0 E} = \frac{\epsilon_0 (\epsilon_r - 1) E}{\epsilon_0 E}$$

$$\chi_e = (\epsilon_r - 1)$$



**01. (e)**

**Sol:** Given:  $R_H = 3.66 \times 10^{-4} \text{ m}^3/\text{coulomb};$

$$\rho = 8.93 \times 10^{-3} \Omega\text{-m};$$

$$B = 0.8 \text{ T};$$

Find Hall angle?

$$\text{Hall angle } \tan \theta_H = \frac{E_H}{E_x} = \mu B$$

$$\tan \theta_H = \mu B = \frac{R_H}{\rho} \times B \quad \left( \because \mu = \frac{R_H}{\rho} \right)$$

$$\tan \theta_H = \frac{3.66 \times 10^{-4}}{8.93 \times 10^{-3}} \times 0.8$$

$$= 0.0327$$

$$\theta_H = \tan^{-1}(0.0327)$$

$$\theta_H = 1.8729^\circ$$

**02. (a)**

**Sol:**

- (i) The minimum energy of a photon required for intrinsic excitation is the forbidden-gap energy  $E_G(\text{eV})$  of semiconductor material.

The wavelength  $\lambda_c$  of a photon whose energy corresponds to  $E_G$  is given by

$$\lambda_c = \frac{1.24}{E_G} \left[ \begin{array}{l} \lambda_c \text{ in microns} \\ E_G \text{ in electron volts} \end{array} \right]$$

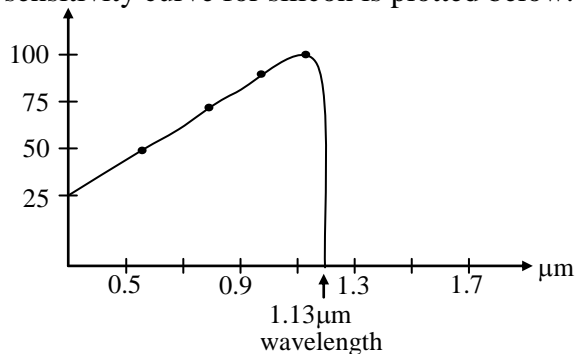
If the wavelength  $\lambda$  of the radiation exceeds  $\lambda_c$ , then the energy of the photon is less than  $E_G$  and such a photon cannot cause a valence electron to enter the conduction band.

Hence  $\lambda_c$  is called the critical, or cutoff wavelength or long wavelength threshold of the material

For silicon  $E_G = 1.1 \text{ eV}$

$$\text{Hence } \lambda_c = 1.13 \mu\text{m}.$$

The spectral sensitivity curve for silicon is plotted below:



- (ii) Given  $\lambda = 2537 \text{ \AA} = 0.2537 \mu\text{m}$

No. of photons = 10,000

spectral sensitivity = 6mA/W

$\therefore$  Energy of one photon

$$E_G = \frac{1.24}{0.2537} = 4.89 \text{ eV/photon}$$



$$\begin{aligned}\therefore \text{Total energy of the photons} &= 4.89 \text{ eV/photon} \times 10,000 \text{ photons} \\ &= 4.89 \times 10^4 \text{ eV} \\ \therefore \text{Total no. of electrons} &= 4.89 \times 10^4 \times 6 \times 10^{-3} \\ &= 293.4 \\ &\cong 293 \text{ electrons.}\end{aligned}$$

## 02. (b)

**Sol:** Garnet is a group of minerals that have been used since the Bronze Age as gemstones and abrasives. Garnets species are found in many colors including red, orange, yellow, green, blue, purple, brown, black, pink and colorless.

Garnets are nesosilicates having the general formula  $X_3Y_2(\text{SiO}_4)_3$ . The X site is usually occupied by divalent cations ( $\text{Ca}^{2+}, \text{Mg}^{2+}, \text{Fe}^{2+}, \text{Mn}^{2+}$ ) and the Y site by trivalent cations ( $\text{Al}^{3+}, \text{Fe}^{3+}, \text{Cr}^{3+}, \text{Mn}^{3+}, \text{V}^{3+}$ ) in an octahedral/tetrahedral framework with  $[\text{SiO}_4]^{4-}$  providing the tetrahedral.

They crystallize in the isometric system, having three axes that are all of equal length and perpendicular to each other.

Garnets do not show cleavage, so when they fracture under stress, sharp irregular pieces are formed. Because the chemical composition of garnet varies, the atomic bonds in some species are stronger than in others. As a result, this mineral group shows a range of hardness on the Mohs Scale of about 6.5 to 7.5.

Garnets can be made in the lab by powdering  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{SiO}_2$ . The powder is then placed inside gold or platinum tubes which are welded shut. (Gold and platinum are used since they do not melt and corrode at high temperatures and do not suffer oxidation). The capsule is then placed in a hydraulic press and brought to a pressure of 80-50,000 atm. An electrical current is run through the sample to attain temperatures of 1200 to 1400°C.

Yttrium iron garnet (YIG),  $\text{Y}_3\text{Fe}_2(\text{FeO}_4)_3$ , another important garnet, the five iron(III) ions occupy two octahedral and three tetrahedral sites, with the yttrium (III) ions coordinated by eight oxygen ions in an irregular cube. The iron ions in the two coordination sites exhibit different spins, resulting in magnetic behaviour. YIG is a ferrimagnetic material having a Curie temperature of 550 K. By substituting specific sites with rare earth elements, for example, Gadolinium, interesting magnetic properties can be obtained.

### Applications of Garnets:

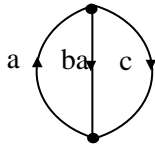
- Gadolinium gallium garnet,  $\text{Gd}_3\text{Ga}_2(\text{GaO}_4)_3$ , which is synthesized for use in magnetic bubble memory.
- Yttrium aluminium garnet (YAG),  $\text{Y}_3\text{Al}_2(\text{AlO}_4)_3$ , is used for synthetic gemstone. When doped with neodymium ( $\text{Nd}^{3+}$ ), these Y Al-garnets are useful as the lasing medium in lasers.
- The Garnet group is a key mineral in interpreting the genesis of many igneous and metamorphic rocks.
- Garnets are also useful in defining metamorphic facies of rocks.
- Pure crystals of garnet are used as gemstones.
- Garnet sand is a good abrasive, and a common replacement for silica sand in sand blasting
- Mixed with very high pressure water, garnet is used to cut steel and other materials in water jets.
- Garnet sand is also used for water filtration media.



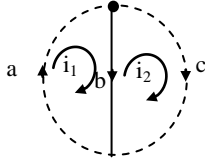
02. (c)

Sol:

Graph of the given network is



Tree



Tie – set matrix

$$[B] = \begin{matrix} i_1 \\ i_2 \end{matrix} \begin{bmatrix} a & b & c \\ 1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}$$

$$[Z_b] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 2 \end{bmatrix}_{3 \times 3} \quad [I_{\text{links}}] = \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}_{2 \times 1}$$

$$[V_s] = \begin{bmatrix} +4 \\ -3i_x \\ -3 \end{bmatrix} \quad [I_s] = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}_{3 \times 1}$$

LHS:

$$[B][Z_b][B]^T = \begin{bmatrix} 1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}_{2 \times 3} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 2 \end{bmatrix}_{3 \times 3} \begin{bmatrix} 1 & 0 \\ 1 & -1 \\ 0 & 1 \end{bmatrix}_{3 \times 2}$$

$$= \begin{bmatrix} 2 & -1 \\ -1 & 3 \end{bmatrix}_{2 \times 2}$$

$$[B][Z_b][B]^T [I_{\text{line}}] = \begin{bmatrix} 2 & -1 \\ -1 & 3 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} 2i_1 - i_2 \\ -i_1 + 3i_2 \end{bmatrix}_{2 \times 1} \quad \text{----- (1)}$$

RHS:

$$[B][V_s] - [B][Z_b][I_s] = \begin{bmatrix} 4 & -3i_x \\ 3i_x & -3 \end{bmatrix}_{2 \times 1} - \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} 4 & -3i_x \\ 3i_x & -3 \end{bmatrix}_{2 \times 1} \quad \text{----- (2)}$$

LHS = RHS

$$\begin{bmatrix} 2i_1 - i_2 \\ -i_1 + 3i_2 \end{bmatrix} = \begin{bmatrix} 4 - 3i_x \\ 3i_x - 3 \end{bmatrix} \quad \text{--- (3)}$$

$$\begin{bmatrix} 2i_1 - i_2 \\ -i_1 + 3i_2 \end{bmatrix} = \begin{bmatrix} 4 - 3i_x \\ 3i_x - 3 \end{bmatrix} \quad \text{--- (4)}$$





Link equation:  $i_2 = i_x$  -----(5)

Solving (3) (4) and (5)

$$i_1 = 3A, i_2 = -1A, i_x = -1A$$

Now branch currents are given by

$$[B]^T [I_{\text{link}}] = [I_b]$$

$$\begin{bmatrix} 0 & 0 \\ 1 & -1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 3 \\ -1 \end{bmatrix} = \begin{bmatrix} j_a \\ j_b \\ j_c \end{bmatrix}$$

$$j_a = 3A, j_b = 4A, j_c = -1A$$

**03. (a)**

**Sol:**

**(i)**

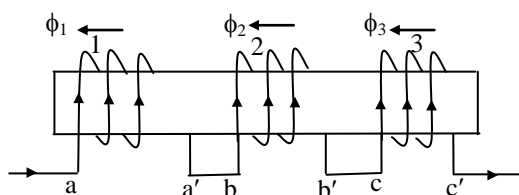


Fig (1)

Let the self inductance of each coil be  $L$  and  $L = 0.2H$  (given)

Mutual inductance between, Coil – 1 and Coil – 2 =  $M_{12}$

Coil – 2 and Coil– 3 =  $M_{23}$

Coil – 3 and Coil – 1 =  $M_{31}$

In fig(i)

Let the effective inductances be  $L_{\text{eff1}}$ ,  $L_{\text{eff2}}$  and  $L_{\text{eff3}}$  and their expressions are given as

$$L_{\text{eff1}} = L + M_{12} + M_{31}$$

$$L_{\text{eff2}} = L + M_{12} + M_{23}$$

$$L_{\text{eff3}} = L + M_{31} + M_{23}$$

First two in series

$$L_{\text{eff1}} + L_{\text{eff2}} = 2L + 2M_{12} + M_{31} + M_{23} = 0.6$$

$$2M_{12} + M_{31} + M_{23} = 0.2 \dots\dots(1)$$

When all coils are in series

$$L_{\text{eff1}} + L_{\text{eff2}} + L_{\text{eff3}} = 3L + 2M_{12} + 2M_{23} + 2M_{31} = 1$$

$$= M_{12} + M_{23} + M_{31} = 0.2 \dots\dots\dots(2)$$

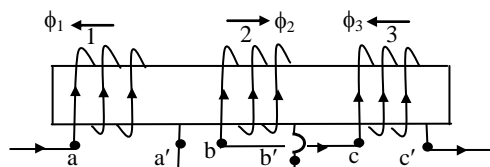
When terminals of first two coils are interchanged

Initial connections

New connections

$a' - b$  and  $b' - c$

$a' - b'$  and  $b - c$



Fig(1)

$$M_{12} \rightarrow -Ve, \quad M_{23} \rightarrow -Ve, \quad M_{31} \rightarrow +ve$$

So,

$$L_{\text{eff1}} = L - M_{12} + M_{31}$$



$$Le'ff_2 = L - M_{12} - M_{23}$$

$$Le'ff_3 = L - M_{23} + M_{31}$$

$$Le'ff_1 + Le'ff_2 + Le'ff_3 = 3L - 2M_{12} - 2M_{23} + 2M_{31} = 0.5$$

$$2M_{12} + 2M_{23} - 2M_{31} = 0.1$$

$$M_{12} + M_{23} - M_{31} = 0.05 \text{ -----(3)}$$

Solving equations (1), (2) and (3)

$$(1) \& (2) \rightarrow M_{12} = 0$$

$$\text{then } M_{23} + M_{31} = 0.2$$

$$M_{23} - M_{31} = 0.05$$

$$M_{23} = 0.125,$$

$$M_{31} = 0.075$$

$$K_1 = \frac{M_{12}}{\sqrt{LL}} = 0,$$

$$K_2 = \frac{M_{23}}{\sqrt{LL}} = \frac{0.125}{0.2} = 0.625$$

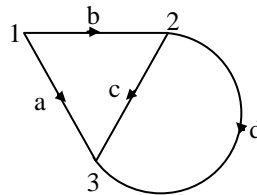
$$K_3 = \frac{M_{31}}{\sqrt{LL}} = \frac{0.075}{0.2} = 0.375$$

(ii)

**Sol: Graph**

In the given circuit, there are three principle nodes and five branches. The graph of the circuit can be given as

$$A = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & -1 & 1 & 1 \\ -1 & 0 & -1 & -1 \end{bmatrix}$$

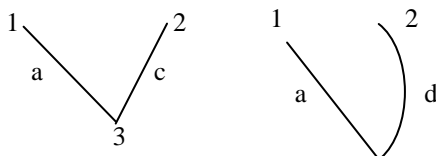
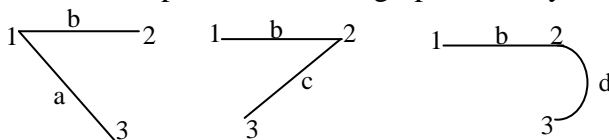


$$A_r = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & -1 & 1 & 1 \end{bmatrix} \quad A_r^T = \begin{bmatrix} 1 & 0 \\ 1 & -1 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}$$

$$A_r \cdot A_r^T = \begin{bmatrix} 2 & -1 \\ -1 & 3 \end{bmatrix}$$

$$\text{The number of trees} = \det(A_r A_r^T) = 6 - 1 = 5$$

Five trees are possible for this graph and they are given by





**03. (b)**

**Sol:** Linear Region current expressions in the MOSFET

$$I_D = \mu C_{ox} \frac{W}{L} \left[ (V_{GS} - V_{TH}) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

$$\text{Saturation Region: } I_D = \mu C_{ox} \frac{W}{2L} (V_{GS} - V_{TH})^2$$

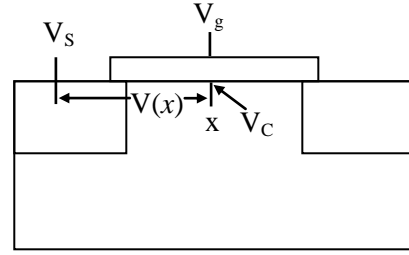


Figure 1: Concentration contours in Linear Region. A uniform narrow channel exists.

KVL:

$$V_G - V_S = V_G - V_C + V_C - V_S$$

$$V_G - V_S = V_{GS}$$

$$V_G - V_C = V_{GC}$$

$$V_C - V_S = V(x)$$

$$V_{GS} = V_{GC} + V(x) \text{ or } V_{GS} - V(x) = V_{GC}$$

Total charge density at x on capacitor ( $C_{OX}$ ) is  $Q_T(x)$ :

$$Q_T(x) = V_{GC} C_{OX} = (V_{GS} - V(x)) C_{OX}$$

$$Q_T(x) = Q(x)_{\text{mobile}} + Q(x)_{\text{depletion}}$$

$$Q(x)_{\text{mobile}} = \text{mobile electron charge in channel at } x$$

$$Q(x)_{\text{mobile}} = [V_{GS} - V(x) - V_{TH}] C_{OX}$$

Use mobile charge to get current:

$$J_n = q\mu_n E + qD_n \frac{dn}{dx} = q\mu_n E \text{ (no diffusion current in the channel)}$$

$$qn(x) = Q(x)_{\text{mobile}} = Q_m(x)$$

$$J_n = Q_m(x) \mu_n E, \text{ but } E = -\frac{dV}{dx}$$

$$J_n = -Q_m(x) \mu \frac{dV}{dx}, \text{ substitute for } Q_m(x)$$

$$J_n = \mu C_{ox} (V_{GS} - V(x) - V_{TH}) \frac{dV}{dx}, \text{ separate variables and neglect } (-) \text{ sign. Consider only the magnitude.}$$

$$J_n dx = \mu C_{ox} [(V_{GS} - V_{TH}) - V(x)] dV$$

Due to continuity,  $J_n$  = constant (no hole current or no generation, recombination). Integrating from source to drain or from  $x = 0$  to  $x = L$ , where  $L$  = gate length:

$$J_n \int_0^L dx = \mu C_{ox} \int_{V(0)}^{V(L)} [(V_{GS} - V_{TH}) - V(x)] dV$$

$$V(L) = V_{DS}, V(0) = 0$$

$$J_n \int_0^L dx = \mu C_{ox} \int_0^{V_{DS}} [(V_{GS} - V_{TH}) - V(x)] dV$$

$$J_n L = \mu C_{ox} \left[ (V_{GS} - V_{TH}) V - \frac{V^2}{2} \right]_0^{V_{DS}} \Rightarrow J_n = \frac{\mu C_{ox}}{L} \left[ (V_{GS} - V_{TH}) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

$$I_D = J_n W \text{ (W = device Width)}$$

$$J_n \text{ for channel is Amp/cm since } Q_m = \text{Charge/cm}^2$$

$$I_D \text{ for Linear Region: } I_D = \mu C_{ox} \frac{W}{L} \left[ (V_{GS} - V_{TH}) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

**03. (c)**

**Sol:** Piezo means pressure. Piezoelectricity implies the production of electric field in a crystal by applying pressure.

- When certain crystals are subjected to stress (or) tension in a specific direction, they produce opposite kinds of charges at the opposite faces in a perpendicular direction.
- The charges produced on each face are always equal in magnitude and are proportional to the total force applied.
- Materials which gets polarized when subjected to mechanical deformation are called piezoelectric materials.
- Only those crystal classes which don't have center of inversion (that is non-Centro-symmetrical crystals) show this piezoelectric property. There are 20 point groups in nature which exhibit this phenomenon.
- In inverse piezoelectric effect, when an electric field applied to the crystal in a specific direction, the crystal gets strained in a perpendicular direction. This is called electrostriction.
- Piezoelectricity is related to symmetry of crystal and it is excluded from all structures having a centre of symmetry because in a Centro symmetric system, the opposite ends in every direction are identical and hence the application of tension or compression produces no polarization at all.

#### **Application of piezoelectric materials:**

- We can produce high frequency oscillations in quartz or barium titanate. An alternating potential difference of 50,000 volt at a frequency of 3 MHz is imposed between the foils at the two ends of a quartz crystal which begins to vibrate rapidly. If the natural frequency of the mechanical vibrations of them, on is equal to applied ac, then on account of resonance, the vibrations are well maintained, such an arrangement is used for stabilizing frequencies in transmitting radio stations and also as standards of frequency.
  - Ultrasonic are used in Non-Destructive Testing (NDT) of materials in the industry and as a diagnostic aid in medicine,
  - In the construction of SONAR (Sound Navigation and Ranging), in under water communication, in the construction of crystal microphones, phonograph reproducers and sound pickups, the piezoelectric materials are widely used.
- The SAW devices are performing similar functions as bulk acoustic wave devices like delay lines, dispersive delay lines, frequency filters, oscillator in the fields like communications and radar, since both depend on the ability to store energy, information on the slowly propagating acoustic wave.

Given data is:

Dimensions = 5 mm × 5 mm × 1.25 mm,

Force F = 5N,

Charge sensitivity = 150 pC/N,

Voltage sensitivity,  $g = 12 \times 10^{-3} \text{ Vm/N}$ ,

Permittivity,  $\epsilon = 12.5 \times 10^{-9} \text{ F/m}$

Charge, Q = ?,

Capacitance, C = ?

$$\text{Pressure } P = \frac{F}{\text{area}} = \frac{5}{25 \times 10^{-6}} = 0.2 \text{ MN/m}^2$$

$$\text{Voltage, } V = g \times P = 12 \times 10^{-3} \times 1.25 \times 10^{-3} \times 0.2 \times 10^6 \\ = 3 \text{ Volts}$$

$$\text{Charge, } Q = \text{Charge sensitivity} \times \text{Force} \\ = 150 \times 10^{-12} \times 5 = 750 \text{ pC}$$

$$\text{Capacitance } C = Q / V = \frac{750 \text{ pC}}{3} = 250 \text{ pF}$$



**04. (a)**

**Sol:** As  $V_{AB} = V_{BC} = V_{CA} = 100 \text{ V}$  and KVL,

$V_{AB} + V_{BC} + V_{CA} = 0$ , they must be phase displaced by  $120^\circ$  with each other

Let  $V_{AB} = 100 \angle 0^\circ$

$V_{BC} = 100 \angle 120^\circ$

$V_{CA} = 100 \angle -120^\circ$

Line current,  $I_L = 5 \angle \theta \text{ A}$

$|V_{BC}| = |I_L| \times |j\omega L|$

$100 = 5 \times (2\pi \times 50 \times L)$

$L = \frac{1}{5\pi} \text{ H}$

$L = 63.66 \text{ mH}$

$V_{BC} = I_L \times (j\omega L)$

$100 \angle 120^\circ = 5 \angle \theta \times 20 \angle 90^\circ$

$\theta = 30^\circ$

$I_L = 4.33 + j2.5$

Since,  $V_{AB} = 100 \angle 0^\circ$

$R = \frac{100}{4.33} = 23.09 \Omega$

$X_C = \frac{100}{2.5} = 40 \Omega$

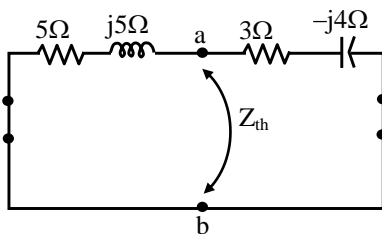
$C = \frac{1}{2\pi \times 50 \times 40} = 79.57 \mu\text{F}$

Power consumed =  $\frac{V_{AB}^2}{R} = \frac{100^2}{23.09} = 433.08 \text{ W}$

**04. (b)**

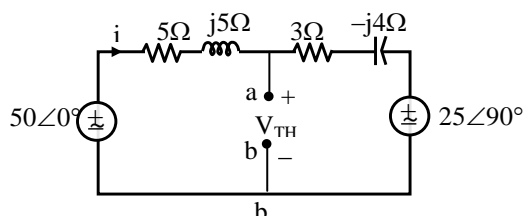
**Sol:** In an AC network, maximum power transfer takes place when,  $Z_L = \text{Conjugate of } (Z_{Th})$

In the given network,  $Z_{Th}$  can be calculated by



$$Z_{TH} = Z_{ab} = (5 + j5) \parallel (3 - j4) \\ = (4.23 - j1.15) \Omega$$

$$Z_L = \text{Conjugate } (Z_{TH}) = 4.23 + j1.15 \Omega$$





$$i = \frac{50 \angle 0^\circ - 25 \angle 90^\circ}{(5 + j5) + (3 - j4)}$$
$$= (5.77 - j3.846) \text{ A}$$

$$V_{TH} = 50 \angle 0^\circ - (5 + j5) \times (5.77 - j3.846)$$
$$= 9.805 \angle -78.69^\circ$$

$$\text{Maximum power transferred to Load} = \frac{V_{TH}^2}{4R_{TH}}$$
$$= \frac{(9.805)^2}{4 \times 4.23} = 5.68 \text{ W}$$

**04. (c)****Sol:**

Nanomaterials having wide range of applications in the field of electronics, fuel cells, batteries, agriculture, food industry, and medicines, etc... It is evident that nanomaterials split their conventional counterparts because of their superior chemical, physical, and mechanical properties and of their exceptional formability.

**(i) Fuel cells:**

A fuel cell is an electrochemical energy conversion device that converts the chemical energy from fuel (on the anode side) and oxidant (on the cathode side) directly into electricity. The heart of fuel cell is the electrodes. Microbial fuel cell is a device in which bacteria consume water-soluble waste such as sugar, starch and alcohols and produces electricity plus clean water. Carbon nanotubes (CNTs) have chemical stability, good mechanical properties and high surface area, making them ideal for the design of sensors and provide very high surface area due to its structural network. Since carbon nanotubes are also suitable supports for cell growth, electrodes of microbial fuel cells can be built using of CNT. Due to three-dimensional architectures and enlarged electrode surface area for the entry of growth medium, bacteria can grow and proliferate and get immobilized. Multi walled CNT scaffolds could offer self-supported structure with large surface area through which hydrogen producing bacteria (e.g., E. coli) can eventually grow and proliferate. Also CNTs and MWCNTs have been reported to be biocompatible for different eukaryotic cells.

**(ii) Catalysis:**

Higher surface area available with the nanomaterial counterparts, nano-catalysts tend to have exceptional surface activity. For example, reaction rate at nano-aluminum can go so high, that it is utilized as a solid-fuel in rocket propulsion. Nano-aluminum becomes highly reactive and supplies the required thrust to send off payloads in space.

**(iii) Phosphors for High-Definition TV:**

The resolution of a television, or a monitor, depends greatly on the size of the pixel. These pixels are essentially made of materials called “phosphors,” which glow when struck by a stream of electrons inside the cathode ray tube (CRT). The resolution improves with a reduction in the size of the pixel, or the phosphors. Nano-crystalline zinc selenide, zinc sulfide, cadmium sulfide, and lead telluride synthesized by the sol-gel techniques are candidates for improving the resolution of monitors.

**(iv) Next-Generation Computer Chips:**

The microelectronics industry has been emphasizing miniaturization, whereby the circuits, such as transistors, resistors, and capacitors, are reduced in size. By achieving a significant reduction in their size, the microprocessors, which contain these components, can run much faster, thereby enabling computations at far greater speeds.



**(v) Elimination of Pollutants:**

Nanomaterials possess extremely large grain boundaries relative to their grain size. Hence, they are very active in terms of their chemical, physical, and mechanical properties. Due to their enhanced chemical activity, nanomaterials can be used as catalysts to react with such noxious and toxic gases as carbon monoxide and nitrogen oxide in automobile catalytic converters and power generation equipment to prevent environmental pollution arising from burning gasoline and coal.

**(vi) Sun-screen lotion:**

Prolonged UV exposure causes skin-burns and cancer. Sun-screen lotions containing nano-TiO<sub>2</sub> provide enhanced sun protection factor (SPF) while eliminating stickiness. The added advantage of nano skin blocks (ZnO and TiO<sub>2</sub>) arises as they protect the skin by sitting onto it rather than penetrating into the skin. Thus they block UV radiation effectively for prolonged duration. Additionally, they are transparent, thus retain natural skin color while working better than conventional skin-lotions.

**(vii) Sensors:**

Sensors rely on the highly active surface to initiate a response with minute change in the concentration of the species to be detected. Engineered monolayers (few Angstroms thick) on the sensor surface are exposed to the environment and the peculiar functionality (such as change in potential as the CO/anthrax level is detected) is utilized in sensing.

**04. (d)**

**Sol:** Given that germanium diode is in Reverse biased,

from the circuit,  $I = I_o + I_R$

differentiate w.r.t to temperature T,

$$\frac{dI}{dT} = \frac{dI_o}{dT} + \frac{dI_R}{dT}$$

As  $I_R$  is Independent of T, i.e.  $\frac{dI_R}{dT} \rightarrow 0$

$$\therefore \frac{dI}{dT} = \frac{dI_o}{dT} \rightarrow (1)$$

Also it is given that, reverse saturation current of diode increases by 0.11°/c,

$$\therefore \frac{1}{I_o} \frac{dI_o}{dT} = 0.11 \rightarrow (2)$$

And Temperature dependences of reverse current is 0.07°/c

$$\therefore \frac{1}{I} \frac{dI}{dT} = 0.07 \rightarrow (3)$$

from equation (1), (2) and (3),

$$0.11 I_o = 0.07 I \rightarrow (4)$$

substituting equation (4) in  $I = I_o + I_R$ ,

$$\text{we get, } I_R = \frac{4}{11} I$$

since  $I = 5 \mu A$

$$I_R = \frac{4}{11} \times 5 \mu A = \frac{20}{11} \mu A$$

$$\therefore R = \frac{V}{I_R} = \frac{10 \times 11}{20} \times 10^6 = 5.5 M\Omega$$

Hence leakage resistance shunting the diode is 5.5MΩ



**05. (a)**

**Sol:** First general solution

$$i(t) = I_{ss}(t) + I_{tr}(t)$$

$$i(t) = \frac{100}{\sqrt{5^2 + 5^2}} \sin(500t + \phi - \theta) + Ae^{-t/\tau}$$

$$|Z| = \sqrt{5^2 + 5^2} = \sqrt{50}$$

$$\theta = \tan^{-1} \left[ \frac{\omega L}{R} \right] = \tan^{-1}[1] = 45^\circ$$

$$T = \frac{L}{R} = \frac{0.01}{5} = \frac{1}{500}$$

$$i(t) = 2\sqrt{50} \sin(500t + \phi - 45^\circ) + Ae^{-500t}$$

$$\text{at } t = 0 \rightarrow i = 0$$

$$0 = 2\sqrt{50} \sin(\phi - 45^\circ) + A$$

$$\text{So, } A = -2\sqrt{50} \sin(\phi - 45^\circ)$$

$$i(t) = 2\sqrt{50} \sin(500t + \phi - 45^\circ) - 2\sqrt{50} \sin(\phi - 45^\circ) e^{-500t}$$

$$\text{Now put } \phi = 0^\circ$$

$$i(t) = 2\sqrt{50} \sin(500t - 45^\circ) + 2\sqrt{50} e^{-500t}$$

$$i(t) = 14.14 \sin(500t - 45^\circ) + 10e^{-500t}$$

**05. (b)**

**Sol: Types of Nano Materials:**

- 1. Zero dimensional(0-D):** These nanomaterials have Nano-dimensions in all the three directions. Metallic nanoparticles including gold and silver nanoparticles and semiconductor such as quantum dots are the perfect example of this kind of nanoparticles. Most of these nanoparticles are spherical in size and the diameter of these particles will be in the 1-50 nm range. Cubes and polygons shapes are also found for this kind of nanomaterials.
- 2. One dimensional (1-D):** In these nanostructures, one dimension of the nanostructure will be outside the nanometer range. These include nanowires, nanorods, and nanotubes. These materials are long (several micrometer in length), but with diameter of only a few nanometer. Nanowire and nanotubes of metals, oxides and other materials are few examples of this kind of materials
- 3. Two dimensional (2-D):** In this type of nanomaterials, two dimensions are outside the nanometer range. These include different kind of Nano films such as coatings and thin-film-multilayers, nano sheets or nano-walls. The area of the nano films can be large (several square micrometer), but the thickness is always in nano scale range
- 4. Three Dimensional (3-D):** All dimensions of these are outside the nano meter range. These include bulk materials composed of the individual blocks which are in the nanometer scale (1-100 nm)





**05. (c)**

**Sol:** Given  $V_{BE(sat)} = 0.8 \text{ V}$

$$\beta_{(sat)} = 100$$

$$V_{CE(sat)} = 0.2 \text{ V}$$

for transistor remains in saturation

$$I_{Bmin} = \frac{5 - 0.8}{100k\Omega} = 42\mu\text{A}$$

$$\text{and } I_{Cmin} = \mu I_B = 4.2 \text{ mA}$$

$$\text{Hence } I_{Csat} \leq 4.2 \text{ mA}$$

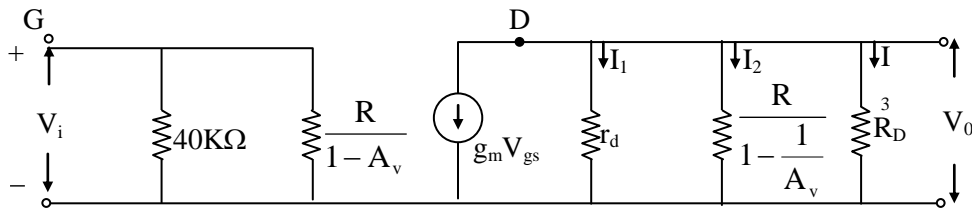
$$I_{Csat} = \frac{10 - 0.2}{R_C} \leq 4.2 \text{ mA}$$

$$R_C \geq 2.33k\Omega$$

$\therefore$  Minimum value of  $R_C = 2.33 \text{ k}\Omega$

**05. (d)**

**Sol:** Drawing the equivalent circuit of given FET,



$$(R_D = 10K\Omega, R = 50K\Omega)$$

From the circuit, using KCL at drain terminal, we have

$$-g_m V_{gs} = I_1 + I_2 + I_3$$

$$= \frac{V_0}{r_d} + \frac{V_0}{R A_v} + \frac{V_0}{R_D}$$

$$-g_m V_{gs} = V_0 \left[ \frac{1}{r_d} + \frac{1}{R_D} + \frac{A_v - 1}{R A_v} \right]$$

$$-g_m = \frac{V_0}{V_{gs}} \left[ \frac{1}{r_d} + \frac{1}{R_D} + \frac{A_v - 1}{R A_v} \right]$$

$$= A_v \left[ \frac{1}{r_d} + \frac{1}{R_D} \right] + \frac{A_v - 1}{R} \quad \left( \because \frac{V_0}{V_{gs}} = A_v \right)$$

$$-g_m + \frac{1}{R} = A_v \left[ \frac{1}{R} + \frac{1}{r_d} + \frac{1}{R_D} \right]$$

$$A_v \left[ \frac{1}{50K\Omega} + \frac{1}{5K\Omega} + \frac{1}{10K\Omega} \right] = \frac{-30}{5K\Omega} + \frac{1}{50K\Omega} \quad (\because \mu = g_m r_d)$$

$$\therefore A_v = -18.7$$



**05. (e)**

$$\begin{aligned}\text{Sol: } H_c &= H_0 \left[ 1 - \left( \frac{T}{T_c} \right)^2 \right] \\ \Rightarrow \left[ 1 - \left( \frac{T}{T_c} \right)^2 \right] &= \frac{H_c}{H_0} \Rightarrow \left( \frac{T}{T_c} \right)^2 = 1 - \frac{H_c}{H_0} \\ \Rightarrow \frac{T}{T_c} &= \sqrt{1 - \frac{H_c}{H_0}} \\ \Rightarrow T &= T_c \sqrt{1 - \frac{H_c}{H_0}} = 12 \times \sqrt{1 - \frac{200 \times 10^3}{250 \times 10^3}} = 5.4\text{K}\end{aligned}$$

**05. (f)**

**Sol: Properties and requirements of good insulating materials:**

The requirement of good insulating materials can be classified as electrical, mechanical, thermal and chemical.

**1. Electrical properties:**

- Electrically, the insulating material should have high resistivity to reduce the leakage current and high dielectric strength to enable it to withstand higher voltage without being punctures or broken down.
- Further, the insulator should have small dielectric loss.

**2. Mechanical properties:**

- Since the insulators are used on the basis of volume and not weight, a low density is preferred.
- The insulators should also have small thermal expansion to prevent mechanical damage.
- Further, it should be non-ignitable, or if ignitable, it should be self extinguishable.

**3. Thermal properties:**

- A uniform viscosity for liquid insulators ensures uniform thermal and electrical properties.
- Liquid and gaseous insulators are used also used as coolants. For example, transformer oil, hydrogen and helium are used both for insulation and cooling purposes. For such materials, good thermal conductivity is a desirable property.

**4. Chemical properties:**

- Chemically, the insulators should be resistant to oil, liquids, gas fumes, acids and alkalies.
- It should not deteriorate by the action of chemicals in soils or by contact with other metals.
- The insulator should not absorb water particles, since water lowers the insulation resistance and the dielectric strength.
- Insulating materials should have certain mechanical properties depending on the use to which they are put. Thus when used for electric machine insulation, the insulator should have sufficient mechanical strength to withstand vibration. Good heat conducting property is also desirable in such cases.
- Materials with large electronic and ionic polarizabilities and therefore large permittivity are used for making dielectric capacitors. Titanium oxide which has a permittivity of about 100 is a good example of such a material.
- The use of molecules with a permanent dipole moment is not desirable because of the possibility of large dielectric losses at high frequencies.



**06. (a)**

**Sol:**

(i)  $R = 2\Omega$ ,  $L = 1\text{mH}$ ,  $C = 0.4\ \mu\text{F}$

$V(t) = 20\sin\omega t$

For a series R-L-C circuit,

(A) Resonant frequency.  $\omega_0 = \frac{1}{\sqrt{LC}}$

$$= \frac{1}{\sqrt{1 \times 10^{-3} \times 0.4 \times 10^{-6}}}$$

$$= 50,000 \text{ rad/sec}$$

(B) Lower half power frequency,

$$\omega_1 = \frac{R}{2L} - \sqrt{\left(\frac{R}{2L}\right)^2 + \left(\frac{1}{\sqrt{LC}}\right)^2}$$

$$= 49000 \text{ rad/sec}$$

Upper half power frequency,

$$\omega_2 = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \left(\frac{1}{\sqrt{LC}}\right)^2}$$

$$= 51000 \text{ rad/sec}$$

(C) Q - factor =  $\frac{1}{R} \sqrt{\frac{L}{C}} = 25$

Bandwidth =  $\omega_2 - \omega_1 = \frac{R}{L} = 2000 \text{ rad/sec}$

(D) Amplitude of current at  $\omega_0$  is given by  $I_0 = \frac{V_{\text{rms}}}{R} = \frac{20}{2(\sqrt{2})} = 7.07 \text{ A}$

Amplitude of current at  $\omega_1$  and  $\omega_2$  is given by,  $I = \frac{I_0}{\sqrt{2}} = \frac{10}{\sqrt{2}} = 5 \text{ A}$

(ii) The current through the capacitor I given by an expression,

$I(t) = C \frac{dv}{dt}$  where  $C = 1\text{mF}$

From  $t = 0$  to  $t = 1 \text{ sec}$

$V(t) = 10t$

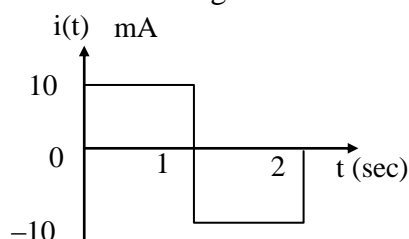
$I(t) = 10 \text{ mA}$

From  $t = 1 \text{ sec}$  to  $t = 2 \text{ sec}$

$v(t) = -10t + 20$

$I(t) = -10\text{mA}$

The current wave form is given as below

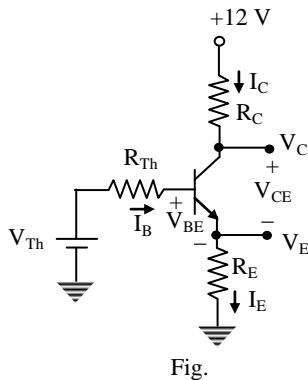




**06. (b)(i)**

**Sol:** Let  $R_1 = 90 \text{ k}\Omega$ ,  $R_2 = 45 \text{ k}\Omega$ ,  $R_C = 3.3 \text{ k}\Omega$ ,  
 $R_E = 3 \text{ k}\Omega$

**Analysis:** Thevenin equivalent of the given circuit:



$$V_{Th} = \frac{R_2 \times 12V}{R_1 + R_2}$$

$$= \frac{45k \times 12V}{90k + 45k} = 4V$$

$$R_{Th} = R_1 \parallel R_2 = 30 \text{ k}\Omega$$

**Step (1):** KVL for base-emitter loop:

$$V_{Th} - I_B R_{Th} - V_{BE} - (1 + \beta) I_B R_E = 0 \dots \dots \dots (1)$$

$$[\because I_E = (1 + \beta) I_B]$$

$$\Rightarrow I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + (1 + \beta) R_E}$$

$$= \frac{4V - 0.7V}{30k\Omega + (101 \times 3k\Omega)}$$

$$= \frac{3.3V}{333k\Omega} = 9.9 \mu A \dots \dots (2)$$

$$I_C = \beta I_B = 100 \times 9.9 \mu A = 0.99 \text{ mA} \dots \dots \dots (3)$$

$$\& I_E = (1 + \beta) I_B = 101 \times 9.9 \mu A \approx 1 \text{ mA} \dots \dots (4)$$

**Step (2):** KVL at emitter of BJT in Fig.:

$$V_E = I_E R_E = 1 \text{ mA} \times 3k\Omega = 3V \dots \dots \dots (5)$$

$$\text{Consider } V_{BE} = V_B - V_E \dots \dots \dots (6)$$

$$\therefore V_B = V_{BE} + V_E = 0.7 \text{ V} + 3 \text{ V} = 3.7 \text{ V} \dots \dots (7)$$

**Step (3):** KVL for collector-loop of BJT in Fig.5(d):

$$V_{CC} - I_C R_C - V_C = 0 \dots \dots \dots (8)$$

$$\therefore V_C = V_{CC} - I_C R_C$$

$$= 12 \text{ V} - 0.99 \text{ mA} \times 3.3k\Omega$$

$$V_C = 8.733V \dots \dots \dots (9)$$



(ii)

Sol:

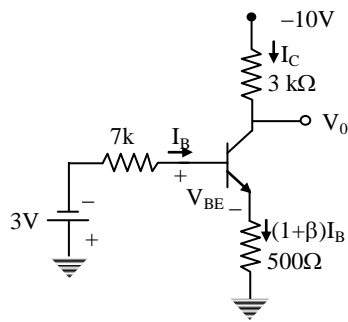


Fig.

(A) KVL for base-emitter loop of BJT:

$$-3V - (I_B \times 7k\Omega) - V_{BE} - ((1+\beta)I_B \times 500\Omega) = 0$$

$$I_B (7k + 101 \times 0.5k) = -3.7V$$

$$\therefore I_B = \frac{-3.7V}{57.5k\Omega} = -0.0643478mA = -64.3478\mu A$$

**Note:** The transistor used in the circuit is an n-p-n transistor and the base current,  $I_B$  is found to be negative, hence the base-emitter junction reverse biased.

$+V_{CC}$  supply is  $-10V$  which is negative, hence base-collector junction is forward biased.

It implies transistor operates in inverse active region.

(B) From the given data, calculation of  $V_0$  is not possible.

06. (c)

Sol: **Unit cell:** Smallest numbers of atoms are arranged in a repetitive manner.

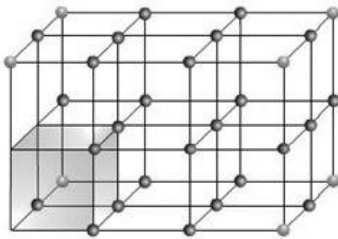


Fig: Space lattice

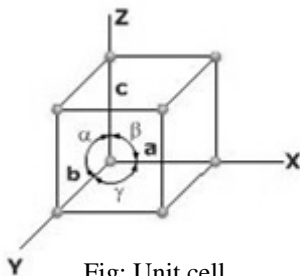


Fig: Unit cell

$a, b, c$  = lattice parameter(s),

$\alpha, \beta, \gamma$  = interfacial angle(s)

**Effective number of atoms / lattice point in cubic unit cell :**

1. Simple cubic structure:



$$8 \text{ atoms at the corners} \times \frac{1}{8} = 1 \text{ atom}$$

Therefore, the unit cell of simple cubic structure contains one atom.

## 2. Body centered cubic structure (B.C.C.):

$$8 \text{ atoms at the corners} \times \frac{1}{8} = 1 \text{ atom}$$

$$1 \text{ centre atom} = 1 \text{ atom}$$

$$\therefore \text{Total} = 2 \text{ atoms}$$

Therefore, the unit cell of B.C.C. structure contains two atoms.

## 3. Face centered cubic structure (F.C.C.):

$$8 \text{ atoms at the corners} \times \frac{1}{8} = 1 \text{ atom}$$

$$6 \text{ face centered atoms} \times \frac{1}{2} = 3 \text{ atoms}$$

$$\therefore \text{Total} = 4 \text{ atoms}$$

Therefore, the unit cell of F.C.C. structure contains four atoms.

### Atomic packing factor of Si material:

Si is a diamond cubic structure material. In diamond cubic structure 8 atoms are arranged at corners and 6 atoms are arranged at face centers and 4 atoms are arranged inside unit cell on 4 body

diagonals with each atom located at  $\frac{a}{4}, \frac{a}{4}, \frac{a}{4}$  from corner.

Effective number of atoms

$$n = \frac{1}{8} \times 8 + \frac{1}{2} \times 6 + 4 = 8 \text{ atoms}$$

Relationship between atomic radius (R) and lattice parametrical

$$8R = \sqrt{3}a$$

$$\Rightarrow R = \frac{\sqrt{3}a}{8} = \frac{\sqrt{3} \times 5.43 \times 10^{-10}}{8}$$

$$= 1.1756 \times 10^{-10} \text{ m}$$

$$V_{uc} = a^3 = \left( \frac{8R}{\sqrt{3}} \right)^3$$

$$= (5.431 \times 10^{-10})^3$$

$$\text{Atomic packing factor} = \frac{n \times \frac{4}{3} \pi R^3}{a^3}$$

$$= \frac{8 \times \frac{4}{3} \pi (1.175 \times 10^{-10})^3}{(5.431 \times 10^{-10})^3}$$

$$= 0.34$$

$$\text{Theoretical density} = \frac{n \times AW}{AN \times V_{uc}}$$

$$\text{Atomic weight} = 2 \times 14 = 28 \text{ g/mol}$$



$$= \frac{8 \times 28 \times 10^{-3}}{6.023 \times 10^{23} \times (5.431 \times 10^{-10})^3}$$

$$= 2322 \text{ kg / m}$$

**07. (a)**

**Sol:**

- (i) The conductivity of a semiconductor is given by,

$$\sigma = (n\mu_n + p\mu_p)q$$

As the conductivity is proportional to the concentration of free carries, ' $\sigma$ ' can be increased or decreased by varying n or p i.e by varying electron or hole concentration thus conductivity modulation is change in conductivity, by changing electron or hole concentration.

The two most important methods for varying n and p are -

- (i) To change the temperature of a semiconductor

- (ii) To illuminate the semiconductor and thereby generate new electron - hole pairs.

- (1) A semiconductor whose conductivity increases with increase in temperature is called a thermistor.

A thermistor has a negative temperature coefficient of resistance.

It has extensive use in

- Thermometry
- The measurement of Microwave-frequency power
- As a thermal relay
- In control devices activated by changes in temperature.

commercial thermistors consist of sintered mixtures of oxides like NiO, Mn<sub>2</sub>O<sub>3</sub>, Co<sub>2</sub>O<sub>3</sub>

- (2) A heavily doped semiconductor can exhibit a positive temperature coefficient of resistance, as under these circumstances the material acquires metallic properties and resistance increases because of decrease in carries mobility with temperature.

Such a device is called sensistor.

- (3) If radiation falls upon a semiconductor, its conductivity increases.

This photo conductive effect is explained as follows:

Radiant energy supplied to the semiconductor ionizes covalent bonds: i.e these bonds are broken, and hole electron pairs in excess of those generated thermally are created.

These increased current carries decrease the resistance of the material & hence such a device is called photo resistor or photoconductor.

There are three important application such a device. It is used as

- To measure a fixed amount of illumination (as with light meter)
- To record a modulating light intensity (as a sound track), &
- As an ON-OFF light relay (as in a digital or control circuit).

Cadmium sulfide cell, lead sulfide cell K selenium cell are widely used as photo conducting devices.

- (ii) First we find for T = 300 K

$$n_i^2 = N_c N_v \exp\left(\frac{-E_g}{kT}\right)$$

$$n_i^2 = (4.7 \times 10^{17})(7.0 \times 10^{18}) \exp\left(\frac{-1.42}{0.0259}\right)$$



$$= 5.09 \times 10^{12}$$

So that,  $n_i = 2.26 \times 10^6 \text{ cm}^{-3}$

At  $T = 450\text{K}$ :

The value of  $kT$  at  $450\text{K}$  is

$$kT = (0.0259) \left( \frac{450}{300} \right) = 0.03885 \text{ eV}$$

$$n_i^2 = (4.7 \times 10^{17}) (7.0 \times 10^{18}) \left( \frac{450}{300} \right)^3 \exp \left( \frac{-1.42}{0.03885} \right) = 1.48 \times 10^{21}$$

So that

$$n_i = 3.85 \times 10^{10} \text{ cm}^{-3}$$

**Comment:**

We may note from this example that the intrinsic carrier concentration increased by over 4 orders of magnitude as the temperature increased by  $150^\circ\text{C}$ .

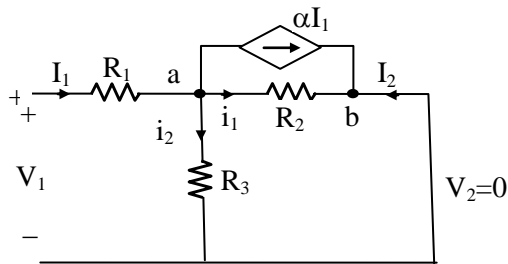
**07. (b)**

**Sol:**  $V_1 = h_{11} I_1 + h_{12} V_2$

$$I_2 = h_{21} I_1 + h_{22} V_2$$

When  $V_2 = 0$

$$h_{11} = \left. \frac{V_1}{I_1} \right|_{V_2=0} = \left. \frac{I_2}{I_1} \right|_{V_2=0}$$



At node  $a$ ,

$$I_1 = i_2 + i_1 + \alpha I_1$$

$$i_2 + i_1 = (1 - \alpha) I_1$$

$$i_1 = (1 - \alpha) I_1 \frac{R_3}{R_2 + R_3} \dots\dots\dots(1)$$

$$i_2 = (1 - \alpha) I_1 \frac{R_2}{R_2 + R_3} \dots\dots\dots(2)$$

Applying KVL

$$V_1 = I_1 R_1 + i_2 R_3$$

$$V_1 = I_1 R_1 + (1 - \alpha) I_1 \cdot \frac{R_2 R_3}{R_2 + R_3}$$

$$h_{11} = \frac{V_1}{I_1} = R_1 + (1 - \alpha) \frac{R_2 R_3}{R_2 + R_3}$$





At node -b

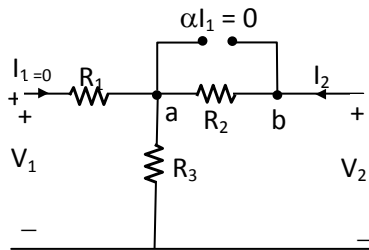
$$\alpha I_1 + i_1 + I_2 = 0$$

$$I_2 = -\alpha I_1 - (1-\alpha)I_1 \frac{R_3}{R_2 + R_3}$$

$$h_{21} = \frac{I_2}{I_1} = -\alpha - (1-\alpha) \frac{R_3}{R_2 + R_3} = \frac{-(\alpha R_2 + R_3)}{R_2 + R_3}$$

when  $I_1 = 0$

$$h_{12} = \left. \frac{V_1}{V_2} \right|_{I_1=0} \quad h_{22} = \left. \frac{I_2}{V_2} \right|_{I_1=0}$$



$$V_1 = I_2 R_3$$

$$V_2 = I_2 (R_2 + R_3)$$

$$h_{12} = \frac{V_1}{V_2} = \frac{R_3}{R_2 + R_3}$$

$$h_{22} = \frac{I_2}{V_2} = \frac{1}{R_2 + R_3}$$

$$\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} = \begin{bmatrix} R_1 + (1-\alpha) \frac{R_2 R_3}{R_2 + R_3} & \frac{R_3}{R_2 + R_3} \\ -\frac{(\alpha R_2 + R_3)}{R_2 + R_3} & \frac{1}{R_2 + R_3} \end{bmatrix}$$

**07. (c) (i)**

**Sol:**

The electrical properties of ceramic products vary from the low loss, high frequency dielectric to semiconductors. Electrical insulator fall into two general classical electrical porcelain for both high and low tension service and the special bodies such as steatite, rutile, cordierite, high alumina, and clinoestatite for high frequency insulation.

### **Dielectric constant:**

Dielectric constant is the ratio of the capacitance of a dielectric compared to the capacitance of air under the same conditions.

A low dielectric constant contributes to low power loss and low loss factor; a high dielectric constant permits small physical size.

The dielectric constant for electrical porcelain varies between 4.1 and 11.0. Some special bodies have reported values of several thousands.

Porcelain has large positive temperature coefficient.

Rutile bodies have large negative coefficient.



By combining capacitor dielectrics having different temperature coefficients it is possible to reduce effect of the temperature change.

**Volume and surface resistivity:**

A volume resistivity of  $10^6$  ohms/cm<sup>3</sup> is considered the lower limit for an insulating material. At room temperature practically all ceramic materials exceed this lower limit. As the temperature of ceramic materials is raised, the volume resistivity decreases; the volume resistivity of soda-lime glasses decreases rapidly with temperature, whereas some special bodies are good insulators (above  $10^6$  ohm/cm<sup>3</sup>) at 700°C. Crystallized alumina has a volume resistivity of  $500$  ohms/cm<sup>3</sup> at 1600°C.

Surface resistivity for dry, clean surface is  $10^{12}$  ohms/cm<sup>2</sup>, At 98% humidity, the surface resistivity may be  $10^{11}$  ohms/cm<sup>2</sup> for a glazed or  $10^9$  ohms/cm<sup>2</sup> for an unglazed piece. The presence of dissolved gases and other deposits also tends to decrease the surface resistivity of ceramic materials.

**High temperature super conductors:**

Mixed oxide of Ba, Ca, Cu exhibit super conduction at about 100 K

**(ii) Polymers are giant molecules made by linking**

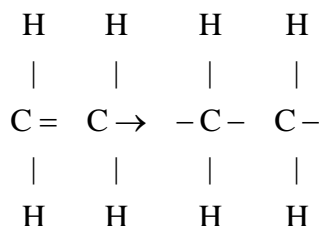
Together a large number of small molecules called monomers. The reaction by which monomer units combine to form polymers is termed polymerization these are mainly three kinds of polymerization processes

(i) Addition polymerization

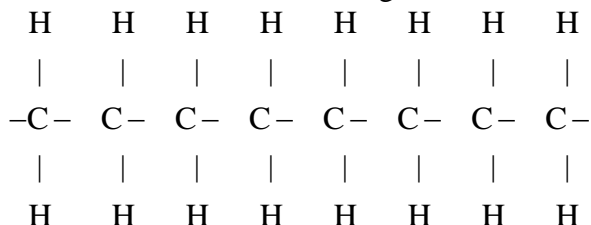
(ii) condensation polymerization and

(iii) copolymerization.

At high temperature and in the presence of catalyst like sulphuric acid or zinc chloride ethylene molecule polymerize to form polyethylene or polythene during polymerization, the double bond is opened up into two single bonds



The monomers are bonded together end-to-end in a polymerization reaction



The degree of polymerization defines the number of repeating monomers in the chain

Polymers have a wide range of uses electrical insulation ropes and filaments carriages, sound proofing materials, vacuum seats, chemical wave, human body implants coating for flying panes polymeric clothing etc.



**08. (a)**

**Sol:**

(i)  $B = \mu H$

$$= \mu_0 \mu_r H$$

i. e.  $B = \mu_0 \mu_r H + \mu_0 H - \mu_0 H$

$$= \mu_0 H + \mu_0 H (\mu_r - 1)$$

$$= \mu_0 H + \mu_0 M$$

Where the magnetisation M is equal to H

$$(\mu_r - 1)$$

i.e.  $B = \mu_0 (H + M)$  -----(1)

The first term on the right side of Eq. (1) is due to external field. The second term is due to the magnetization.

Thus the magnetic induction (B) in a solid is

$$B = \mu_0 (H + M)$$

Hence  $\mu_0 = \frac{B}{H + M}$

The relative permeability

$$\mu_r = \frac{\mu}{\mu_0} = \frac{B/H}{B/H + M} = \frac{H + M}{H} = 1 + \frac{M}{H}$$

$$\mu_r = 1 + \chi$$

(ii) Given data:

Magnetization  $M = 2300 \text{ Am}^{-1}$

Flux density  $B = 0.00314 \text{ Wb m}^{-2}$

The magnetic flux density  $B = \mu_0 (M + H)$

The magnetizing force  $H = \frac{B}{\mu_0} - M = \frac{0.00314}{4\pi \times 10^{-7}} - 2300 = 198.7326 \text{ Am}^{-1}$

The susceptibility  $\chi = \frac{M}{H} = \mu_r - 1$

Where  $\mu_r$  is the relative permeability, i.e.,  $\mu_r = \frac{M}{H} + 1 = \frac{2300}{198.723} + 1 = 12.57334$

The magnetizing force  $H = 198.7326 \text{ Am}^{-1}$

The relative permeability  $\mu_r = 12.57334$

**08. (b)**

**Sol: (i) Paramagnetism:**

- Materials, whose atoms possess permanent dipole moments, are paramagnetic in nature. In the absence of external field, these atomic dipoles are randomly oriented such that net magnetization (M) is zero.
- When an external magnetic field is applied, these atomic dipoles tend to align themselves in the direction of the field, producing net magnetization 'M' in the direction of H, and positive susceptibility.
- Paramagnetic atoms and ions include particles having one electron over and above a completed shell (alkali group), atoms of transition elements, ions of the rare earth elements with incomplete shell etc.
- The magnitude of alignment of atomic dipoles with external field direction is limited by temperature.



- As the temperature increases, thermal agitation of atoms increases and magnetization decreases, there by decreasing susceptibility.
- Thus paramagnetic susceptibility is inversely proportional to temperature

$$\chi \propto \frac{1}{T} \text{ (Curie's law)}$$

$$\text{(or)} \quad \chi = \frac{C}{T} \text{ (or)} \quad \chi = \frac{\mu^2}{3kT}$$

$C \rightarrow$  Curie's constant ;

$\mu \rightarrow$  Atomic dipole moment,

$T \rightarrow$  Absolute temperature

$k \rightarrow$  Boltzman's constant

Thus paramagnetic susceptibility  $\chi$  is +ve and small and depends on temperature.

**Examples:** Liquid Oxygen, Oxygen, Air, Aluminum, Ebonite, Platinum, Tungsten etc.

### **Ferromagnetism & Ferromagnetic materials:**

- These are generally crystalline solids, which are magnetized independent of any external field. i.e.,  $M$  has finite value even when the external  $H$  is zero. (Spontaneous magnetization)
- When an external  $H$  is applied, large  $M$  is produced in the direction of  $H$ . Thus ferromagnetic susceptibility is positive and large. This can be understood in terms of uncompensated electron spins.
- According to quantum theory, strong exchange forces between neighboring spinning electrons tend to make spins parallel (ferromagnetic) or anti-parallel (anti-ferromagnetic) depending upon the number of electrons and the distance between individual electrons.
- Weiss domain theory is most successful in explaining ferromagnetism.

**Examples:** Iron, Cobalt, Nickel, Gaddlinium.

(ii) Given data:

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ Fm}^{-1}$$

$$\epsilon_r = 1.0000684$$

$$N = 2.7 \times 10^{25} \text{ atoms per m}^3$$

$$\alpha_e = \frac{\epsilon_0(\epsilon_r - 1)}{N}$$

$$\alpha_e = \frac{8.854 \times 10^{-12} (1.0000684 - 1)}{2.7 \times 10^{25}}$$

$$\alpha_e = \frac{8.854 \times 10^{-12} \times 0.684 \times 10^{-4}}{2.7 \times 10^{25}}$$

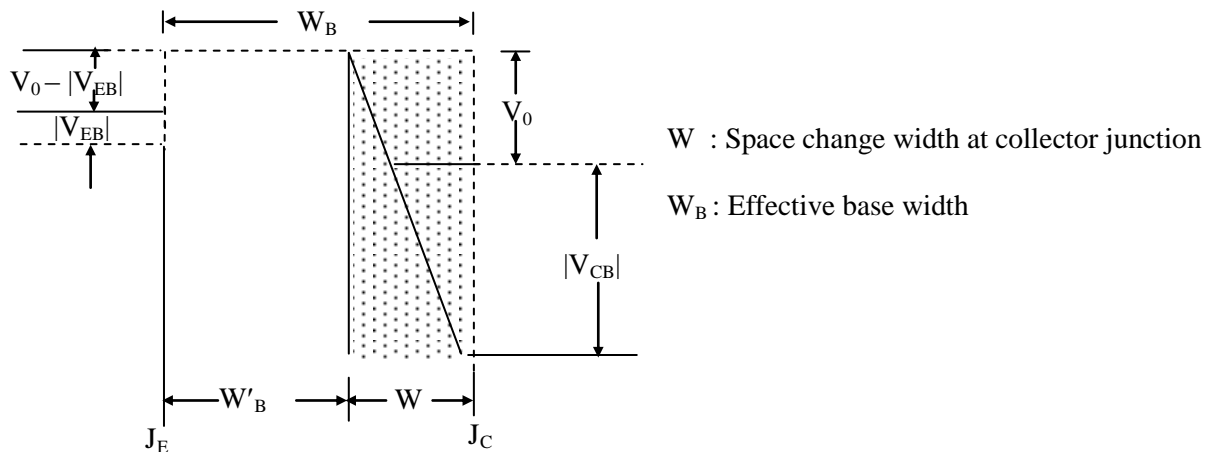
$$= 2.243 \times 10^{-41} \text{ Fm}^2$$



**08. (c)**

**Sol:** Consider a p-n-p BJT with emitter junction ( $J_E$ ) in forward biased and collector junction ( $J_C$ ) in reverse biased.

The barrier width at  $J_E$  is negligible compared to space charge width at  $J_C$ . As the doping in the base is substantially smaller than that of collector, the penetration of transition region into the base is much larger than into collector. Hence the collector depletion region is neglected and all immobile charge is indicated in the base region.



If the metallurgical base width is  $W_B$ , then the effective electrical base width is  $W'_B = W_B - W$ .

This modulation of effective base width by the collector voltage is known as base-width modulation or early effect.

The decrease in  $W'_B$  with increasing reverse collector voltage has 3 consequences.

1. There is less chance for recombination within the base region. Hence,  $\alpha$  increases with increasing  $|V_{CB}|$ .
2. The concentration gradient of minority carriers is increased within the base. Since the hole current injected across the emitter is proportional to the gradient of minority carriers at emitter junction, then emitter current  $I_E$  increases with increasing reverse collector voltage.
3. For extremely large voltages, effective electrical base width  $W_B$  may be reduced to zero, causing voltage breakdown in the transistor. This phenomenon is called punch through.

**08. (d)**

**Sol:**

(i) The circuit for  $t > 0$  is shown in Fig.

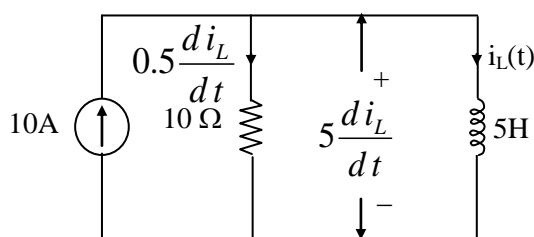


Fig.



Write the nodal equation:

$$0.5 \frac{di_L(t)}{dt} + i_L(t) = 10$$

$$\frac{di_L(t)}{dt} + 2i_L(t) = 20$$

$$i_L(0) = 0, i_L(\infty) = 10 \text{ A}$$

$$\text{Time constant, } \tau = \frac{L}{R} = 0.5 \text{ sec}$$

General formula for step response of 1<sup>st</sup> order circuit:

$$i_L(t) = F.V. + (I.V - F.V) e^{-\frac{t}{\tau}}$$

$$i_L(t) = 10(1 - e^{-2t})$$

Energy stored in L at  $t = \infty$  is

$$= \frac{1}{2} L i^2(\infty)$$

$$= \frac{1}{2} \times 5 \times 100$$

$$= 250 \text{ J}$$

(ii)

$$V_C(0) = 12 \text{ V}$$

For  $t > 0$ , the circuit is shown in Fig. 1.

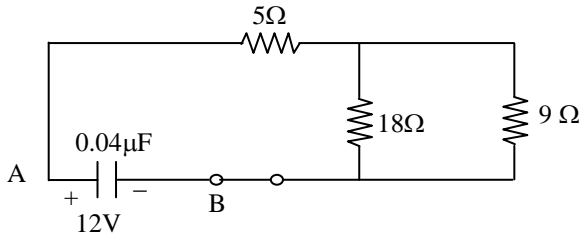


Fig.1

The simplified circuit is shown in Fig. 2

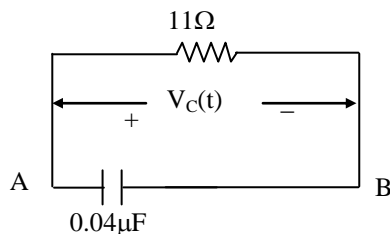


Fig.2

$$V_C(t = 0_+) = 12 \text{ V}, V_C(\infty) = 0$$

$$\begin{aligned} \text{Time constant, } RC &= 11 \times 0.04 \times 10^{-6} \\ &= 0.44 \times 10^{-6} \text{ sec} \end{aligned}$$

$$V_C(t) = 12 e^{-\frac{25}{11}Mt}, t > 0$$

where  $t$  is in  $\mu\text{s}$ .