Physics For Electrical Science, GBPHT121

December 2024

1. Define fermi energy. Give the significance of fermi level.

Ans:- The highest energy level an electron can occupy at absolute zero temperature is known as the Fermi level. It can also be defined as an energy level in which the probability of occupation by an electron is 0.5. The energy of $\bar{e}$ in the Fermi level is called Fermi Energy. This helps to understand the electrical properties of semiconducting materials.

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2. Distinguish between intrinsic and extrinsic semiconductors.

Ans:- An intrinsic semiconductor is a pure form of semiconductor material without any significant impurities or dopants. It possesses electrical conductivity that lies between that of conductors and insulators. Eg: silicon and germanium.

A semiconductor which has undergone doping [addition of impurities] is called extrinsic semiconductor. There are two types of extrinsic semiconductors.

1. n-type semiconductor → $\bar{e}$ are doped eg: Germanium doped with Arsenic

2. p-type semiconductor → holes are doped eg: Ge doped with Al

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3. Write a short note on semiconductor laser.

* It is also called injection laser or homojunction laser.
* Produces ~~by~~ light by stimulated emission
* O/p is highly coherent and monochromatic.
* Pumping → direct conversion (forward biasing)
* Active medium & Active centre → GaAs crystal & ēs.
* Active region → pn junction of GaAs crystal
* Optical resonator → 1 pair of faces is completely polished and the other is roughened.

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4 Ans:- 1. Solar cells are arranged in series or parallel to make solar panels.

2. When connected in series, voltage get added up and I remains constant

3. When connected in parallel, I gets added up and V remains constant.

4. In series, positive pole of one solar cell is connected to negative pole of the next cell

5. In parallel, positive pole of one solar cell is connected to positive pole of the next.

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5. An insulator placed in a capacitor is called a dielectric. Here the ēs are tightly bound to the nucleus of the atom and there are no free ēs ~~at~~ available for conduction of current. eg:- glass, mica, paper etc. Dielectric materials helps in increasing the capacitance.

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6. $B = \mu_0 [H + M]$

For a superconductor, $B = 0$ inside it. According to Meissner effect, the magnetic lines are expelled from the interior of material when it becomes superconductor

$\therefore B = 0, \Rightarrow \mu_0 [H + M] = 0$, $\mu_0 = 4\pi \times 10^{-7}$ H/m

$\therefore [H + M] = 0 \Rightarrow H = -M$ or $\frac{M}{H} = -1$

i.e. $\chi = -1$ which shows ~~superconductors~~

superconductors are diamagnetic nature.

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7.

Spontaneous Emission	Stimulated Emission
(1) The atom de-excites to ground state without the help of external energy	(1) The atom de-excites to ground state with the help of external energy

(2) The emitted photon can move randomly	(2) The emitted photons move in same direction and highly directional.
(3) incoherent radiations are produced	(3) coherent radiations are produced
(4) polychromatic in nature	(4) monochromatic in nature.
(5) $R_{sp} = A_{21} N_2$	(5) $R_{st} = B_{21} N_2 \rho(\nu)$
(6) eg: Sodium Vapour Lamp	(6) Laser beam

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8. (1) Used in remote monitoring & surveillance
(2) Used in cable TV, CCTV, LAN, WAN etc
(3) Used for signalling and decorative purposes.
(4) Used for transfer of infrared energy
(5) Used in defence communication systems in controlling ships, aircrafts etc
(6) Used to examine heart, pancreas etc

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9(a) **Diode Equation**:

Diode equation gives the relation between the current flowing through a diode and the external voltage applied across it.

Total current, $I = I_p + I_n$

where $I_p \propto \Delta P_n$ and $I_n \propto \Delta N_p$

By Boltzmann relation,

$$P_p = P_n e^{\frac{V_B}{V_T}} \quad \text{——— (1)}$$

when there is no biasing, $V_B = V_0$

$\therefore$ (1) becomes $P_p = P_n e^{\frac{V_0}{V_T}}$

V_0 decreases in forward biasing,

$$V_B = V_0 - V$$

P_n increases to $P_n + \Delta P_n$ during forward biasing, $\because$ some of the holes from the P-region enter the n-region

I_p = hole current
I_n = $\bar{e}$ current
ΔP_n = change in hole density in n region
ΔN_p = change in $\bar{e}$ density in p region
P_p = hole density in P region
V_B = Barrier potential
V_T = Voltage equivalent of T
$V_T = \frac{KT}{e}$ and at room temp, $V_T = 26mV$.
$V \rightarrow$ applied voltage

$\therefore$ Hole density

$$P_p = [P_n + \Delta P_n] e^{\frac{V_0 - V}{V_T}}$$

$$P_p = [P_n + \Delta P_n] \cdot e^{\frac{V_0}{V_T}} \cdot e^{\frac{-V}{V_T}}$$

$$P_n e^{\frac{V_0}{V_T}} = [P_n + \Delta P_n] e^{\frac{V_0}{V_T}} \cdot e^{\frac{-V}{V_T}}$$

$$P_n = [P_n + \Delta P_n] e^{\frac{-V}{V_T}}$$

$$P_n e^{\frac{V}{V_T}} = P_n + \Delta P_n$$

$$\therefore \Delta P_n = P_n e^{\frac{V}{V_T}} - P_n$$

$$\Delta P_n = P_n \left[e^{V/V_T} - 1 \right]$$

But $P_p = P_n e^{\frac{V_0}{V_T}}$

$$\therefore P_n = P_p e^{\frac{-V_0}{V_T}}$$

$$\Delta P_n = P_p e^{\frac{-V_0}{V_T}} \left[e^{\frac{V}{V_T}} - 1 \right]$$

~~Similarly~~ hole current $I_p \propto \Delta P_n$

$$\therefore I_p \propto \Delta P_p \, e^{-\frac{V_0}{V_T}} \left[e^{\frac{V}{V_T}} - 1 \right]$$

$$I_p = I_{sp} \left[e^{\frac{V}{V_T}} - 1 \right]$$ where I_{sp} = Proportionality constant.

Similarly electron current,

$$I_n = I_{sn} \left[e^{\frac{V}{V_T}} - 1 \right]$$

$\therefore$ Total current, $I = I_p + I_n$

$$I = I_{sp} \left[e^{\frac{V}{V_T}} - 1 \right] + I_{sn} \left[e^{\frac{V}{V_T}} - 1 \right]$$

$$I = (I_{sp} + I_{sn}) \left[e^{\frac{V}{V_T}} - 1 \right]$$

$I = I_0 \left[e^{\frac{V}{V_T}} - 1 \right]$, $I_0 \rightarrow$ reverse saturation current

$I_0 = I_{sp} + I_{sn}$

$I \rightarrow$ diode current

$I = I_0 \left[e^{\frac{V}{\eta V_T}} - 1 \right]$, $\eta \rightarrow$ material constant

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9(b) $f(E) = \dfrac{1}{\left[e^{(E-E_F)/kT} + 1 \right]}$

$E - E_F = 0.1\,eV$

$f(E) = 2\% = 0.02$

i.e., $0.02 = \dfrac{1}{\left[e^{(0.1eV)/kT} + 1 \right]}$

$0.02 \left[e^{(0.1eV)/kT} + 1 \right] = 1$

$\left[e^{(0.1eV)/kT} + 1 \right] = \dfrac{1}{0.02} = 50$

$e^{(0.1eV)/kT} = 50 - 1 \Rightarrow e^{(0.1eV)/kT} = 49$

$\ln 49 = \dfrac{0.1eV}{kT}$

$T = \dfrac{0.1\,eV}{k . \ln 49} \Rightarrow T = \dfrac{0.1}{8.617 \times 10^{-5} \times \ln 49}$

$T = 298.17\,K$

10(a) ~~Electron den~~ Hole density in the Valence band

$$P = \int_{-\infty}^{E_V} dp = \int_{-\infty}^{E_V} Z(E)\, dE \cdot [1 - F(E)]$$

P → hole density in the valence band

dp → no: of holes available between the energy interval E and E+dE in the valence band

Z(E) dE → density of states in the valence band

[1 − F(E)] → probability of occupancy of holes in the valence band

$$Z(E).dE = \frac{4\pi}{h^3}(2m_h^*)^{3/2}(E_V - E)^{1/2}\, dE$$

$$[1 - F(E)] = e^{\left[\frac{E - E_F}{KT}\right]}$$

$$\therefore P = \int_{-\infty}^{E_V} dp = \int_{-\infty}^{E_V} \frac{4\pi}{h^3}(2m_h^*)^{3/2}(E_V - E)^{1/2}\, dE \cdot e^{\frac{E - E_F}{KT}}$$

$$P = \frac{4\pi}{h^3}(2m_h^*)^{3/2} e^{\frac{-E_F}{KT}} \int_{-\infty}^{E_V} (E_V - E)^{1/2} e^{\frac{E}{KT}} . dE$$

Let $\frac{E_V - E}{KT} = x$, then $\frac{E}{KT} = \left(\frac{E_V}{KT}\right) - x$, $dE = -KT\, dx$

when $E \to E_V$, then $x = 0$ and when $E \to -\infty$, then $x = \infty$

$$\therefore P = \frac{4\pi}{h^3}(2m_h^*)^{3/2} e^{\frac{-E_F}{KT}} \int_{\infty}^{0} (KTx)^{1/2} e^{\left(\frac{E_V}{KT} - x\right)} . -KT\, dx$$

$$P = \frac{4\pi}{h^3}(2m_h^* KT)^{3/2} . e^{\frac{E_V - E_F}{KT}} \int_{\infty}^{0} x^{1/2} . e^{-x}\, dx$$

$$P = \frac{4\pi}{h^3}(2m_h^* KT)^{3/2} e^{\frac{E_V - E_F}{KT}} . \frac{\sqrt{\pi}}{2} = 2\left[\frac{2\pi m_h^* KT}{h^2}\right]^{3/2} . e^{\frac{E_V - E_F}{KT}}$$

10 (b) $n_i = ?$

$T = 300\,k$

$E_g = 1.1\,eV$

$m_n^* = 0.12\,m_e$

$m_p^* = 0.28\,m_e$

$$n_i = 2\left[\frac{2\pi kT}{h^2}\right]^{3/2} (m_n^* m_p^*)^{3/4} e^{\frac{-E_g}{2kT}}$$

$$2\left[\frac{2\pi kT}{h^2}\right]^{3/2} = 2\left[\frac{2\times 3.14 \times 1.38\times 10^{-23} \times 300}{(6.62\times 10^{-34})^2}\right]^{3/2}$$

$$= 2.88\times 10^{70}$$

$$(m_n^* m_p^*)^{3/4} = \left[0.12\times 9.1\times 10^{-31} \times 0.28\times 9.1\times 10^{-31}\right]^{3/4}$$

$$= 6.812\times 10^{-47}$$

$$e^{\frac{-E_g}{2kT}} = e^{\left(-\frac{1.1\times 1.6\times 10^{-19}}{2\times 1.38\times 10^{-23}\times 300}\right)}$$

$$= 5.869\times 10^{-10}$$

$$n_i = 2.88\times 10^{70} \times 6.812\times 10^{-47} \times 5.869\times 10^{-10}$$

$$= 1.1515\times 10^{15}\,m^{-3}$$

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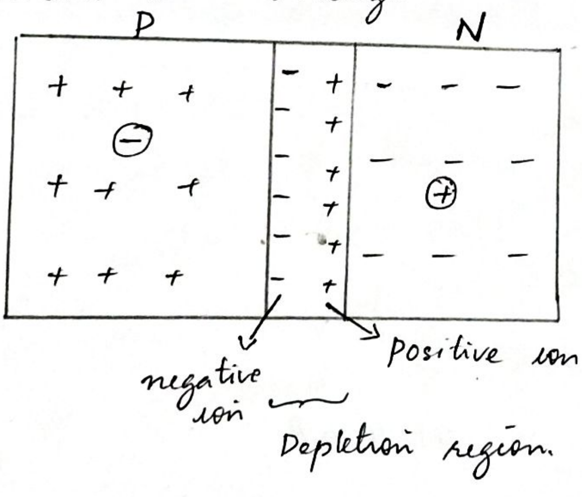
1. 11(a) Tunnel diode is a pn junction diode which exhibits negative resistance region between peak point voltage and valley point voltage in forward and reverse biased condition -

Working

A tunnel diode is heavily doped leading to a large number of majority carriers, most of them are not used during initial recombination. Hence depletion layer will be very narrow. The working principle is tunnelling effect. The movement of valence ēs from E_V to E_C with little or no forward bias voltage is called Tunnelling.

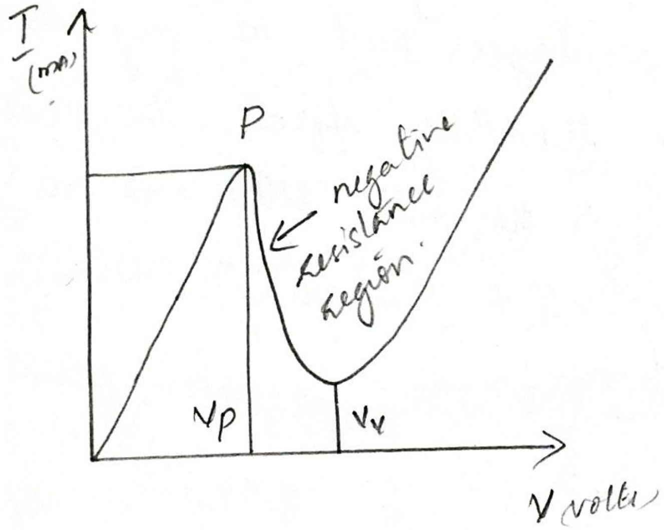


V-I characteristics of Tunnel diode

1. Initially as the forward bias voltage increases, the ēs from n region tunnels through the barrier potential to p region, leading to the increase in current until the peak point P is reached [Peak point → The voltage at which current starts to decrease] Here tunnel diode shows negative resistance

2. when V is increased beyond peak point, V_P, the tunnelling effect decreases and current decreases. This continous until valley point voltage V_V. Between V_P and V_V, the diode shows negative resistance.

3. when V increases beyond V_V, the tunnel diode acts as a normal diode. Here the diode show positive resistance region



1(b) $V_m = V_{rms}\sqrt{2} = 50 \times \sqrt{2} = 70.71$ V

$V_{rms} = 50$ V

$r_f = 10\,\Omega$

$R_L = 980\,\Omega$

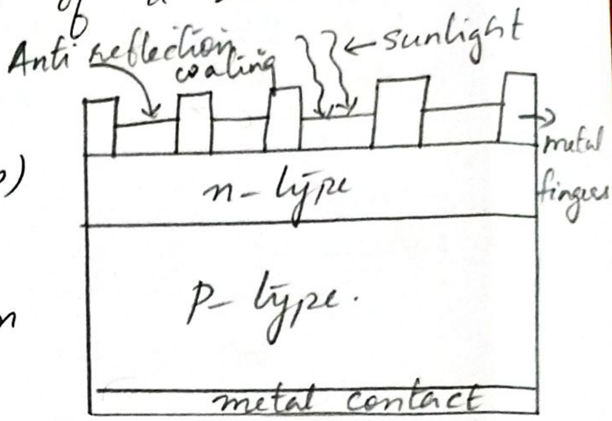
$$I_m = \frac{V_m}{r_f + R_L} = \frac{70.71}{10+980} = 71.4 \text{ mA}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{71.4}{\sqrt{2}} = 50.48 \text{ mA}$$

$$I_{dc} = \frac{2 I_m}{\pi} = \frac{2 \times 71.4}{\pi} = 45.49 \text{ mA}$$

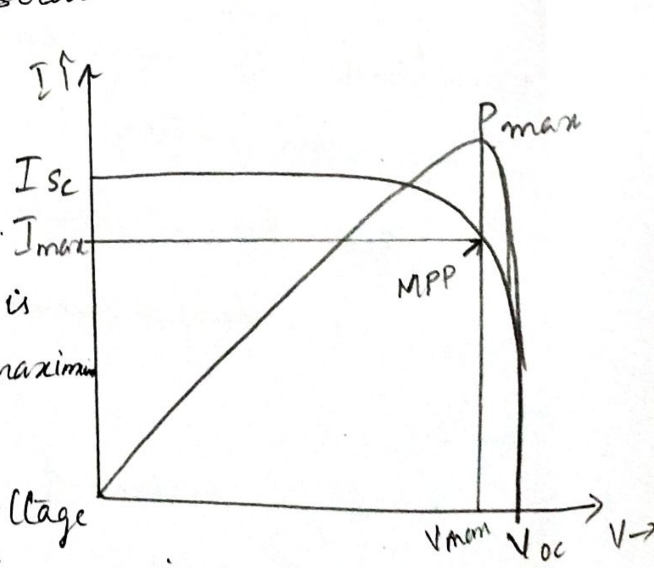
12a Solar cell is a device that converts solar energy to electrical energy.

Working and I-V characteristics of a solar cell



when light falls on the top of semiconductor (n-region) ēs are knocked out from the material. These ēs travel from n-region to p-region through external load, there by completing the whole electric circuit and obtaining electric current.

Consider a solar cell connected to a ammeter, voltmeter and a load resistance and it is exposed to sunlight. If there is no load connected, there will be no current flow as the circuit is open with a voltage of V_{oc}. If the terminals are shorted together, the short circuit current I_{sc} flows
13 without an o/p voltage. In both the cases, no power is delivered by the solar cell.



when a load is connected, a voltage is developed, a current flows in the circuit and there is an o/p power. o/p power is maximum for a specified load resistance.

Let V_{max} and I_{max} be the voltage and current corresponding to the maximum power point. MPP is the condition under which solar cell generates its maximum power P_{max}.

12(b) $\lambda = 654 nm$

$E_g = ?$

$$E_g = \frac{hc}{\lambda e} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{654 \times 10^{-9} \times e} = 1.89 \text{ eV}$$

12(c)

Efficiency of a solar cell

It is the ratio of total power converted by the solar cell to the total power available for energy conversion

Fill factor

It is the ratio of maximum o/p power to the product of open circuit voltage and short circuit current. A text book of Engineering Physics:- Dominic and A Nahari

13a) Clausius Mossotti Relation

It explains the relation between dielectric constant of an insulator and polarizability of atoms comprising it.

We know that the dipole moment of a single atom is proportional to local field or internal field.

i.e, Dipole moment = αE_i where α is the polarizability of the atom.

Bulk polarization, $P = N\alpha E_i$ where 'N' is the no: of atoms / unit volume E_i is the local field / internal field

$$\alpha = \frac{P}{NE_i} = \frac{P}{N\left(E + \frac{P}{3\varepsilon_0}\right)} \quad \text{—— (1)}$$

$$P = \varepsilon_0 E (\varepsilon_r - 1)$$

$$\alpha = \frac{P}{N\left(\frac{P}{\varepsilon_0(\varepsilon_r - 1)} + \frac{P}{3\varepsilon_0}\right)}$$

$$N\alpha = \frac{P}{\frac{P}{\varepsilon_0}\left[\frac{1}{(\varepsilon_r - 1)} + \frac{1}{3}\right)} \Rightarrow \frac{N\alpha}{\varepsilon_0} = \frac{1}{\left(\frac{1}{(\varepsilon_r - 1)} + \frac{1}{3}\right)}$$

$$\frac{N\alpha}{\varepsilon_0} = \frac{1}{\frac{(3 + \varepsilon_r - 1)}{3(\varepsilon_r - 1)}} \Rightarrow \frac{N\alpha}{\varepsilon_0} = \frac{1}{\frac{\varepsilon_r + 2}{3(\varepsilon_r - 1)}}$$

$$\frac{N\alpha}{\varepsilon_0} = \frac{3(\varepsilon_r - 1)}{\varepsilon_r + 2} \Rightarrow \boxed{\frac{N\alpha}{3\varepsilon_0} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2}}$$

13(b) $E = 10^4$

$\varepsilon_r = 3$

$P = ?$

$\varepsilon_0 = 8.85 \times 10^{-12}$

$P = \varepsilon_0 (\varepsilon_r - 1) E$

$= 8.85 \times 10^{-12} \times (3 - 1) \times 10^4$

$P = 1.77 \times 10^{-7}\ C/m^2$

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14(a) Superconductors are those material which shows zero resistance at a particular low temperature and attains maximum conductivity. This phenomenon is called superconductivity

The temperature at which the resistance of a material suddenly drops to zero and the material changes to superconducting nature is called ~~superconductivity~~. ~~eg~~ critical temperature.

eg: $Hg \rightarrow 4.8K$

Critical magnetic field:- It is the strength of the magnetic field required to destroy the superconducting nature of a material at a particular temperature

$$H_C = H_0 \left[1 - \left(T/T_C\right)^2\right]$$

$H_C \rightarrow$ critical field
$H_0 \rightarrow$ field at zero k.
$T \rightarrow$ present temperature
$T_C \rightarrow$ critical temperature

14(b)(1) Cryotron – a fast electrical switching system utilises superconductivity for its operation

(2) MAGLEV → levitated trains for a rapid transit system using superconducting magnets

(3) SQUID → Superconducting quantum Interference device used in medical field, industrial field etc to measure magnetic field of the range 10^{-14} T

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15(a) **Population Inversion**

To get more stimulated emission, the value of $N_2 > N_1$. The situation of getting more number of atoms in the excited state than the number of atoms in the ground state is called population inversion.

Pumping

The process of raising more number of atoms to the excited state from the ground state by an external agency is called pumping

eg: Xenon flash lamp in Ruby laser

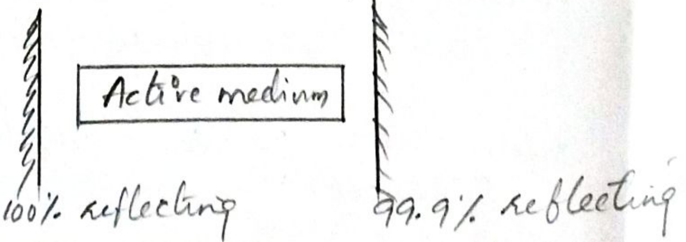
Meta stable state

The atom excited to this state spends time, about milliseconds, ie, nearly 10^{10} times more than in the excited state. Such a state is known as meta stable state

Optical Resonator

The optical resonator consists of a pair of plane or spherical mirrors placed at each end of the lasing medium. One of the mirrors is 100% reflection and the other is 99.9% reflecting which acts as a feedback device to intensify the radiations, thus amplifying it.

The mirrors arranged ⊥r to the optical axis of the active medium.



15.b) Laser beam is used in the fabrication of micro electronic circuit elements and fine trimming of components in integrated circuits. eg: Nd-YAG laser.

He-Ne laser has shown curing effects on tropic ulcers, poorly healing wounds, bone fractures etc.

A finely focused beam can be used as a unique surgical knife, capable of offering bloodless and painless surgery : eg: CO_2, Argon lasers

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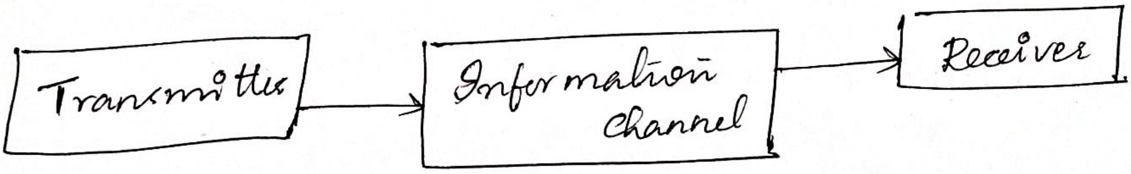
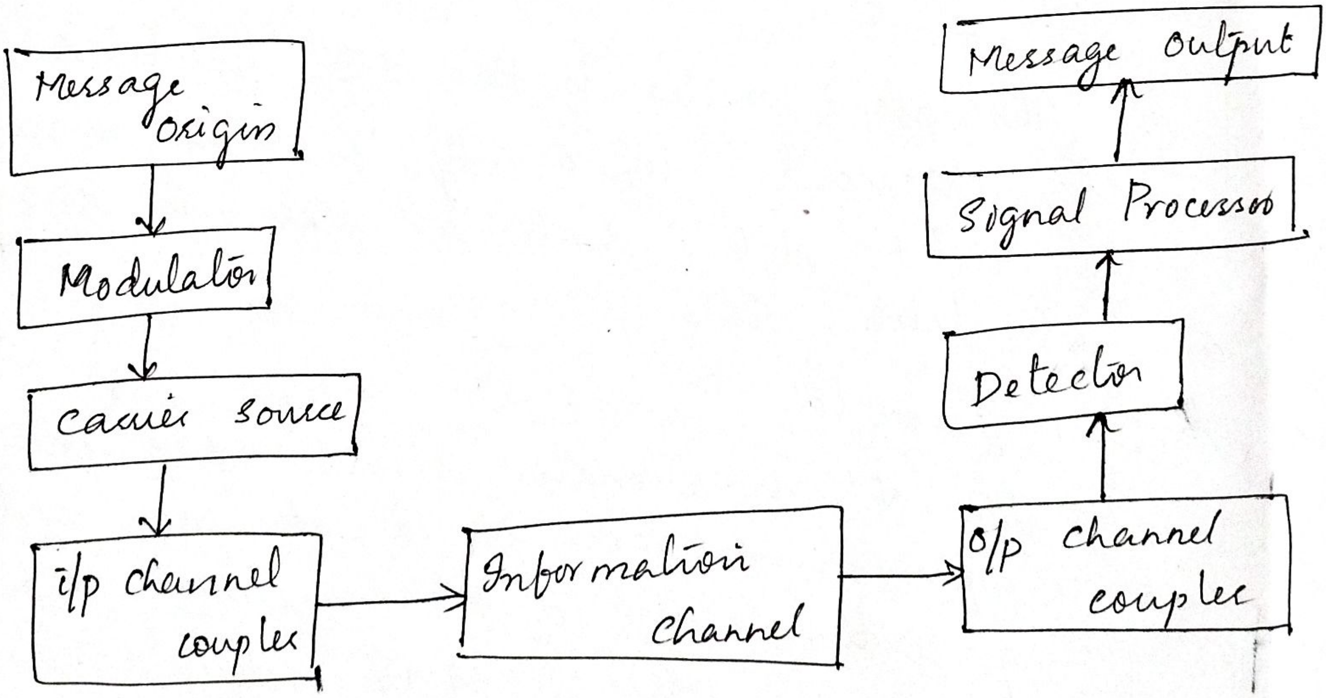
16 (a)





Transmitter :- Here electrical signals are converted to optical format

Information Channel :- It connects transmitter with receiver

Receiver : It connects optical signals to electrical format

Message Origin :- Non electrical are converted to electrical format using transducer
eg: Microphone.

Modulator :- It converts signals to suitable format (encoder to convert electrical to digital format)
It modulate electrical signals with light signals.

Carrier source :- carrier source provides carrier signals to modulate electrical signals. eg: laser diode or LED

I/p channel coupler :- It is connecting device that connects carrier source with information channel.
eg: antenna in broadcasting station.

Information channel :- It is the path that connects transmitter with receiver. It can be varied according to the type of the signal. For optical signals, fibre optic cables are used.

o/p channel coupler : It connects information channel with detector : eg: antenna in our home.

Detector :- Here demodulation takes place, i.e, electrical signals are seperated from optical signals, using photo detector

Signal Processor :- Here required signal is selected and amplified.

Message o/p :- Here electrical signals are converted back to non electrical format using transducer.

If the signals are in digital format, first it is converted to electrical format using decoder

16 (b) $n_1 = 1.53$

$n_2 = 1.39$

$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.53)^2 - (1.39)^2} = \underline{\underline{0.639}}$

$\theta_0 = \sin^{-1}(NA) = \sin^{-1}(0.639) = 39.75^\circ$

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