Thermometry & Fiber optics

3.1 Heat, temperature, temperature scale : Degree celsius, degree Kelvin, degree Fahrenheit.

Thermal Properties of matter
Matter - Everything that exists around us
solids, liquids, gas & plasma
Thermal energy is the heat energy. It is the internal energy of atoms in random motion inside the object.

Heat
- It is a form of energy which produces sensation of hotness.
- Amount of energy absorbed or evolved is called heat denoted by Q.
- Heat is an extensive property.
- Heat is defined as the energy that flows from one body to another body as the result of temperature difference between them.
- SI unit of heat energy is Joule & MKS unit is kcal
In practice CGS unit of heat energy is calorie.

Temperature
- Temperature is a measure of hotness or coldness of a body
- Measured using thermometer
- SI unit Kelvin
- Temperature is intensive property
- Temperature of a body is directly

proportional to the amount of kinetic energy of molecules of body.

Calorie

One calorie is defined as the amount of heat energy required to increase the temperature of one gram of water through 1°C

1 calorie = 4.186 J

kcal

One kilocalorie of heat is defined as the amount of heat energy required to increase the temperature of one kg of water through 1°C.

1 kcal = 4186 J

Absolute zero temperature

The temperature at which pressure & volume of a gas theoretically becomes zero is called absolute zero temperature.

If a gas is cooled then its pressure & volume decreases. It is observed that at -273°C pressure & volume of a gas theoretically becomes zero.

-273°C is minimum possible temperature for all gases.

i.e -273°C = 0°K = 0° absolute

Temperature scales
Thermometer is used to measure temperature

1) Celcius scale (°C) of temperature
Lower fixed Point = 0°C
Upper fixed point = 100°C
The scale is divided into 100 equal parts & each part is called °C.

2) Faherenheit scale (°F)
Lower fixed point = 32 °F
Upper fixed point = 212 °F
Scale is divided into 180 equal parts

3) Kelvin scale of temperature
Lower fixed point = 273 °K
Upper fixed point = 373 °K
Scale is divided into 100 equal parts

Relation between temperature scales

1) Relation between °C & °F

$$°C = \frac{5}{9}(F-32) \quad \text{or} \quad F = \left(\frac{9}{5}°C\right) + 32$$

2) Relation between °C, °F & °K

$$°C = \frac{F-32}{1.8} = K - 273$$

Kelvin or absolute scale of temperature is used where the temperature is measured relative to an arbitarily choosen fixed point called 'triple point of water'.

This fixed point is state where pure water coexists as a mixture of ice, liquid & vapour.

This state occurs at -273 °C

°K = t (°C) + 273

K = temperature in Kelvin

t = temperature in degree celsius

Absolute scale of temperature

lower fixed point is 273 °K

Upper fixed point is 373 °K

The scale is divided into 100 equal parts each part is degree kelvin or degree absolute.

Advantages of Kelvin Temperature

1) The temperature is always positive

2) Gas laws can be explained only using kelvin scale

3) Velocity of sound in air is directly proportional to square root of absolute temperature.

3.2 Modes of heat transfer : Conduction, Convection & Radiation, Applications in daily life.

1) Conduction

Transfer of heat from one part of a body at higher temperature to another part of a body at actual temperature without actual movement of particles conduction takes place in solids.

When heat energy is transfered from one layer to another the temperature in the thermometer goes on increasing.

This state of temperature is called variable state.

After some time, amount of heat absorbed = amount of heat given out. This state of temperature is called as steady state.

For conduction intervening medium is necessary.

Steady state of temperature

Temperature at which rate of heat absorbed by the material is equal to the rate of heat evolved.

Temperature gradient

Change in temperature per unit length of rod

Temperature gradient $\left(\frac{\theta_1 - \theta_2}{d}\right)$

SI unit °K/m

θ_1 = temperature of layer one

θ_2 = temperature of layer two

d = distance between two consecutive la

Amount of heat conducted at steady state depends on:

1) Area of cross-section (A)
2) Temperature gradient $\left(\frac{\theta_1 - \theta_2}{d}\right)$

3) Time for which heat flows through conductor (t).

Good conductors of heat

The materials through which heat can pass easily

eg. copper, iron, steel

Bad conductors

The materials through which heat is not conducted easily is called bad conductor

eg. Plastic, wool, wood

Law of thermal conductivity

The amount of heat flowing at steady state is directly proportional to

1) Area of cross-section i.e $Q \propto A$
2) Temperature difference between the two layers $Q \propto (\theta_1 - \theta_2)$
3) Time for which heat flows $Q \propto t$
4) Inversely proportional to distance between two layers

$$Q \propto \frac{1}{d}$$

$$Q \propto \frac{A(\theta_1 - \theta_2)t}{d}$$

$$Q = \frac{KA(\theta_1 - \theta_2)t}{d}$$

where K is coefficient of thermal conductivity

$$\therefore k = \frac{Q \cdot d}{A(\theta_1 - \theta_2)t}$$

If $A = 1$

$\theta_1 = \theta_2 = 1$

$t = 1$

$d = 1$

$k = Q$

Coefficient of thermal conductivity

It is defined as the amount of heat conducted in one second at steady state of temperature through unit cross sectional area of the material having unit thickness with unit temperature difference between its opposite faces.

Units of thermal conductivity

cal / cm°C s → CGS

kcal / m°C s → MKS

J / m °K s → SI

watt / m°k → SI

J / s → watt

Application of conduction

1) In diesel or petrol engine
2) Immersion heater
3) Safety lamp

2) Convection

The process of transfer of heat energy from a part of body at higher temperature to a part of body at lower temperature with actual movement of particles

Convection takes place in liquids

Types of convection

1) Free convection

It occurs in the fluids at rest

eg. still air in a closed space

2) Forced convection

It occurs in externally controlled steady stream of fluid sent past the hot body

eg. air ventilation from open window

Application of convection

1) Electric fan

2) Refrigerator

3) Air conditioner

4) land & sea breeze

3) Radiation

Radiation is the process of transfer of heat in which heat is transferred from one point to other directly without the necessity of intervening medium

eg. heat radiated from sun.

Application of radiations

1) Thermal radiator, electric bulb, sun

2) White clothes absorb less heat so they are preferred in summer.

3.3 Boyle's law, Charle's law, Gay lussac's law, perfect gas statements equation & simple numerical

Kinetic theory of gases

Postulates:

1) A gas consists of large number of extremely small particles called molecules

2) The gas molecules are perfectly rigid & elastic sphere

3) There is negligible force of attraction between molecules

4) Gas molecules are always in a state of random motion

5) They do not loose kinetic energy after collision

6) After collision gas molecules take a rectilinear path.

Gases expand on heating & their volm increases

Gas has three variables:

Volume (V), Temperature (T), Pressure (P)

NTP

It is normal or standard pressure at sea level.

OR

Pressure exerted by a column of 76 cm of mercury at temperature 0°C is called NTP

1) Boyle's law

At constant temperature, volume of a given mass of a gass is inversely proportional to the pressure.

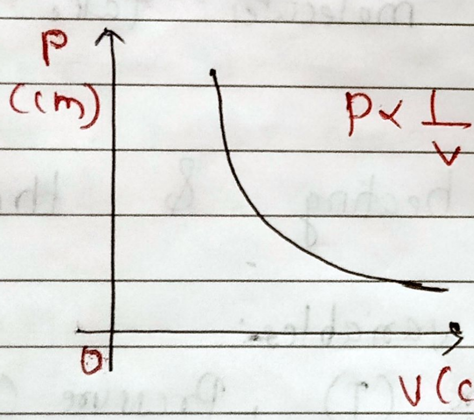
$$V \propto \frac{1}{P}$$

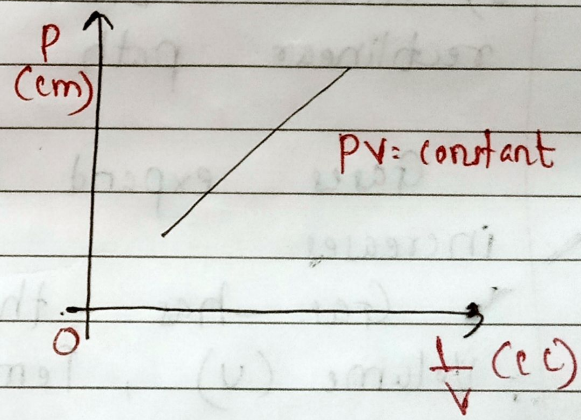
$$V = \frac{k}{P}$$

$$PV = \text{constant}$$

$$P_1V_1 = P_2V_2 = \text{constant}$$

P_1 & V_1 = Initial pressure & volume of gas
P_2 & V_2 = Final pressure & volume of gas





2) Charle's law

A constant pressure volume of gases given mass of gas is directly proportional to its absolute temperature in °K.

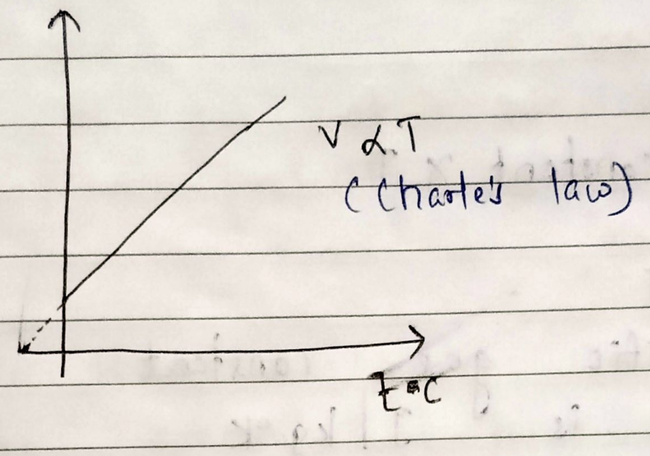
$$V \propto T$$

$$V = kT$$

$$\frac{V}{T} = k \text{ (constant)}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \text{constant}$$

V_1 = volm of gas at temp T_1 in (K)
V_2 = volm of gas at temp T_2 in (K)



3) Gay Lussac's law

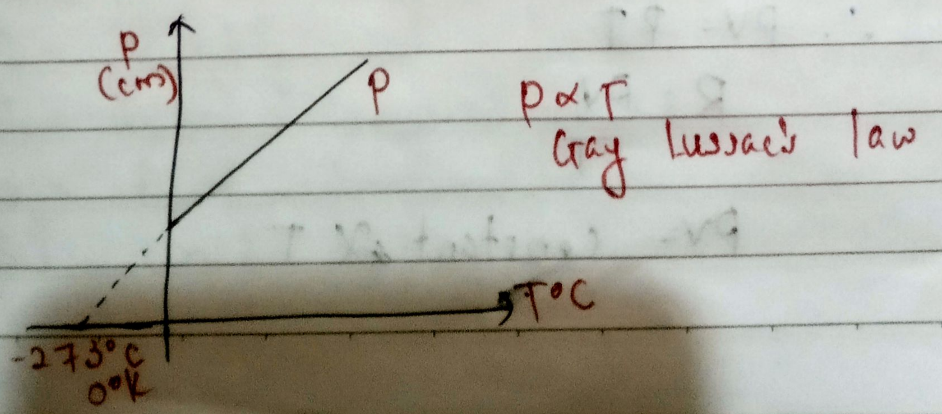
At constant volume pressure (P) of a given mass of a gas is directly proportional to its absolute temperature T in °K.

$$P \propto T$$

$$\frac{P}{T} = \text{constant}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} = \text{constant}$$

P_1 = pressure of gas at temperature T_1 in kelvin
P_2 = Pressure of gas at temperature T_2 in Kelvin



Perfect Gas Equation / General Gas equation

Specific gas constant

According to Gay Lussac's law:

$P \propto T$

According to Charle's law

$V \propto T$

Combining,

$PV \propto T$

$\therefore$ $PV = \text{constant} \times T$

$PV = kT$

k is specific gas constant

Unit of k is J/kg °K

Molar constant or Universal gas constant

Product of molecular weight (M) & specific gas constant is constant for all gases.

$\therefore$ $R = R'M$

$R' = \frac{R}{M}$

Replacing R' by volm of 1 kg mole of gas

$PV = R'T$

At NTP according to Avogadro's hypothesis 1 kg mole of gas occupies volume of $22.4\ m^3$

$\therefore$ $PV = RT$

$R = \frac{PV}{T}$

$PV = \text{constant} \times T$

For 1 gm molecule of gas
$PV = RT$
R is universal gas constant
$R = 8314.9$ J/kg. mole °K
SI unit of R is J/kg. mole °K

Ideal gas
If a gas at constant temp obeys gas law perfectly it is called ideal gas.

Specific heat of gases
The amount of heat required to increase the temperature of unit mass of gas or substance through 1°C or 1°K.
Its unit is Joule/kg°K in SI system

Specific heat at constant volume (Cv)
The quantity of heat required to raise the temperature of 1 kg of gas through 1°C or 1°K keeping its volm constant is called as specific heat at constant volume

$$C_V = \frac{Q}{m(\theta_2 - \theta_1)}$$

Cv specific heat of gas at constant volume
Q = quantity of heat required
θ_1 = initial temperature
θ_2 = final temperature
SI unit J/kg°K.

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Specific heat at constant Pressure (Cp)

The quantity of heat required to raise the temperature of 1 kg of gas through 1°C or 1°K keeping pressure constant is called as specific heat at constant pressure.

$$Cp = \frac{Q}{m(\theta_2 - \theta_1)}$$

Cp = specific heat at constant pressure
Q = quantity of heat required
m = mass of gas in an enclosed cylinder
θ_1 = initial temperature of gas
θ_2 = final temperature of gas

1 cal/gm°K = 1 kcal/kg °K
°K = 4.2 J/gm°K = 4200 J/kg °K

SI unit is J/kg °K.

Ratio of specific heat

$$\frac{C_p}{C_v} = \gamma$$

As $C_p > C_v$, $\gamma > 1$

$\gamma = 1.31$ for triatomic gases like O_3, NO_2, CO_2

$\gamma = 1.41$ for diatomic gases like H_2, N_2, O_2 etc

$\gamma = 1.41$ for air

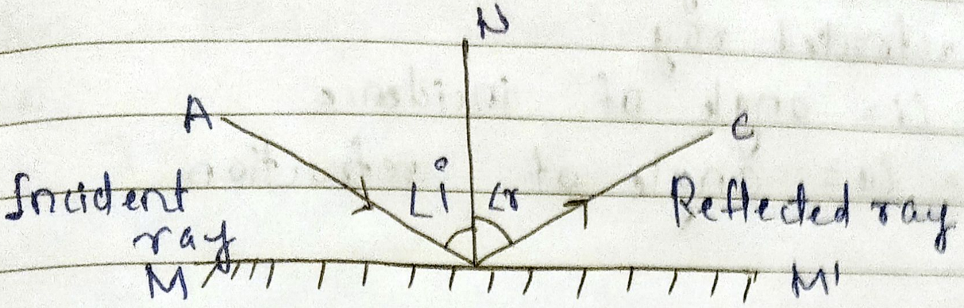
$\gamma = 1.66$ for monoatomic gases like He, Ne

Optics

Law of refraction, Total internal reflection

Reflection

The turning back or bouncing back of light when it encounters a smooth polished surface is called reflection



AO = incident ray

OC = reflected ray

MM' = Reflecting surface

∠AON = ∠i = angle of incidence

∠CON = ∠r = angle of reflection

Laws of reflection

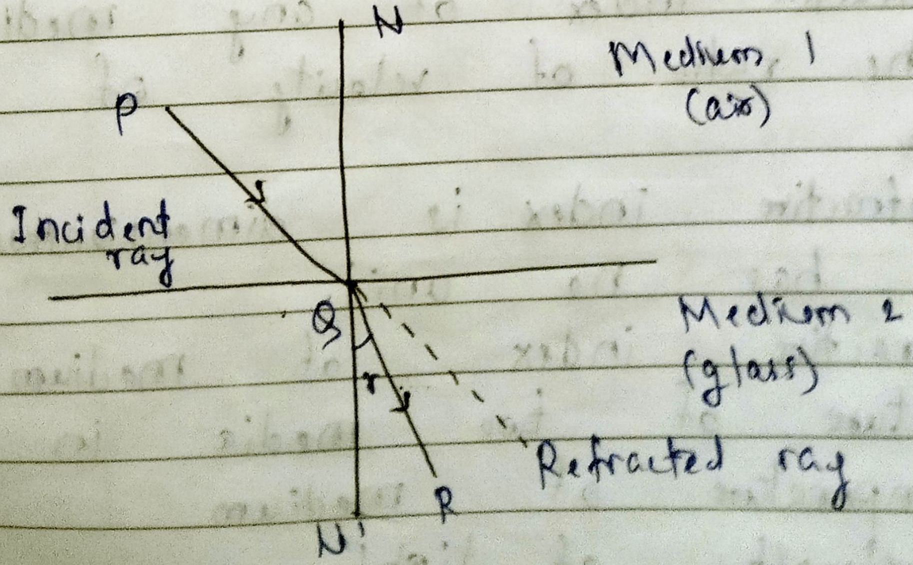
1) Incident ray, reflected ray & normal lie in the same plane.

2) Incident ray, reflected ray lie on opposite sides of normal.

3) Angle of incidenke = angle of reflection

Refraction

Bending of light ray when it travels from one medium to another medium is called refraction



PQ = Incident ray
QR = refracted ray
$\angle PQN = \angle i =$ angle of incidence
$\angle RQN' = \angle r =$ angle of refraction

Laws of refraction (Snell's law)

1) Incident ray, refracted ray & normal to the surface of separation of two media lie in the same plane.

2) Incident ray, refracted ray, lie on the opposite sides of normal.

3) Snell's law of refraction

For any two media, ratio of sine of angle of incidence to the sine of angle of refraction is constant.

$$\frac{\sin i}{\sin r} = \text{constant}$$

The constant is called refractive index

${}^{1}\mu_{2}$ = refractive index of medium 2 with respect to medium 1.

Refractive Index

Refractive index of any medium is defined as the ratio of velocity of light in the medium

Refractive index is dimensionless quantity so it has no unit.

Refractive index of medium depends on-

a) nature of two media in constant.

b) temperature of medium

c) wavelength of light

Relation between wavelength & R I of media

$$\lambda_1 \mu_1 = \lambda_2 \mu_2$$

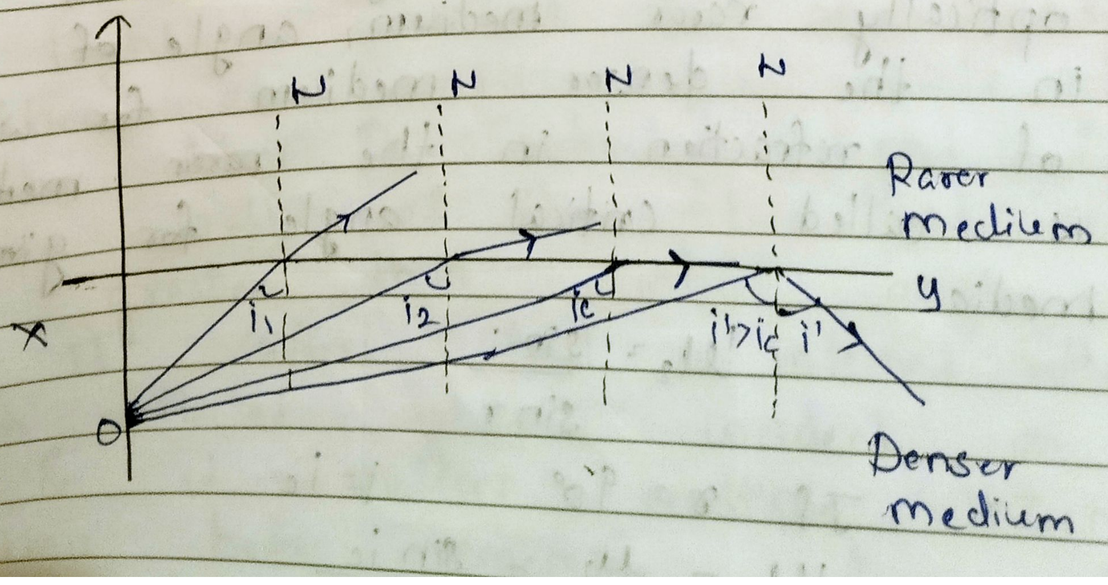
Total Internal Reflection

When a ray of light passing through a denser medium is incident on the surface of a rarer medium at an angle greater than the critical angle, the ray is totally reflected in a denser medium. This phenomenon is called total internal reflection.

Conditions for total internal reflection

1) Ray of light must be travelling from optically denser medium to optically rarer medium

2) Angle of incidence in the denser medium must be greater than critical angle for given pair of media.



According to Snell's law,

$$ {}^2\mu_1 = \frac{\sin r}{\sin i} = \frac{1}{\sin i / \sin r} = \frac{1}{{}^1\mu_2} $$

$$ {}^2\mu_1 \times {}^1\mu_2 = \frac{1}{\sin i / \sin r} = \frac{1}{{}^1\mu_2} $$

$$ {}^2\mu_1 \times {}^1\mu_2 = 1 \quad \& $$

$$ {}^1\mu_2 = \frac{\sin i}{\sin r} = \frac{V_1}{V_2} = \frac{c/V_2}{c/V_1} = \frac{\mu_2}{\mu_1} $$

$$ \frac{\mu_2}{\mu_1} = \frac{\sin c}{\sin 90^\circ} \quad \because \sin 90^\circ = 1 $$

$$ \frac{\mu_2}{\mu_1} = \sin c $$

$$ c = \sin^{-1} \frac{\mu_2}{\mu_1} $$

Critical angle

When ray of light travels from an optically rarer medium, angle of incidence in the denser medium for which angle of refraction in the rarer medium is 90° is called critical angle for given pair of media"

$$ {}^1\mu_2 = \frac{\sin i}{\sin r} $$

If $r = 90^\circ$ $\quad i = i_c$

$$ {}^1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\sin i_c}{\sin 90^\circ} $$

If $\mu_2 = 1$ for air & $\mu_1 = \mu$

$$\frac{1}{\mu} = \frac{\sin i_c}{1}$$

$$\mu = \frac{1}{\sin i_c}$$

$$\sin i_c = \frac{1}{\mu}$$

$$i_c = \sin^{-1}\left(\frac{1}{\mu}\right)$$

Optical fiber

Principle : Total Internal Reflection

It consists of large number of extremely thin fibres of fine quality glass or quartz.

Central part of the fiber is called core & refractive index of material is 1.7

The fiber is coated with a thin layer of material called cladding of lower refractive index.

Core of fiber is optically denser than outer layer.

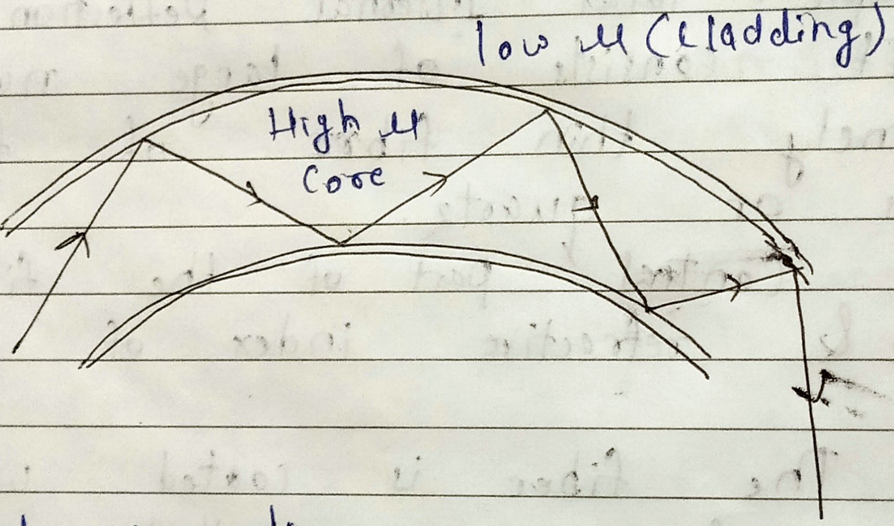
Light is incident at one end of fiber at small angle, it is refracted into the fiber. The refracted light falls on the wall of the fiber at an angle greater than critical angle.

∴ It suffers total internal reflection. Again reflected light is incident on the wall & it suffers multiple internal reflections before emerging from other end of fiber.

It is as if fiber acts as pipe through which light flows.

Uses of optical fiber

1) In endascope for medical examination of inner ~~plate~~ parts of the body of patient.
2) To transmit sound & picture signals over long distances using light pulses.
3) In telecommunication for carrying sound signals coded in light signals.



4) Mechanical inspection
5) Internet
6) Cable television
7) Telephone
8) Lighting & decoration
9) Automotive industry
10) Oil & gas industry.

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Types of optical fiber

Optical fiber

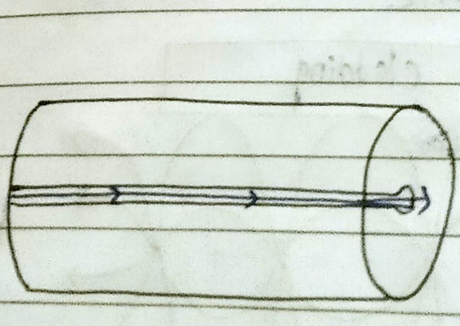
↙ ↘

Step Index fiber   Graded Index fiber

In step index fiber R.I of the core is uniform all along its length. In this type there is sharp decrease in RI of the cladding in comparison with RI of core

Based on the mode of transmission step index fibers have two different types.
1) Single mode step index fiber
2) Multimode step index fiber

Single Mode step index fiber
- diameter of the core is very small (of the order of 10 microns).
- allows transmission of only one light signal through the core.
- this reduces the possibility of reduction in signal strength & allows it to travel long distance.

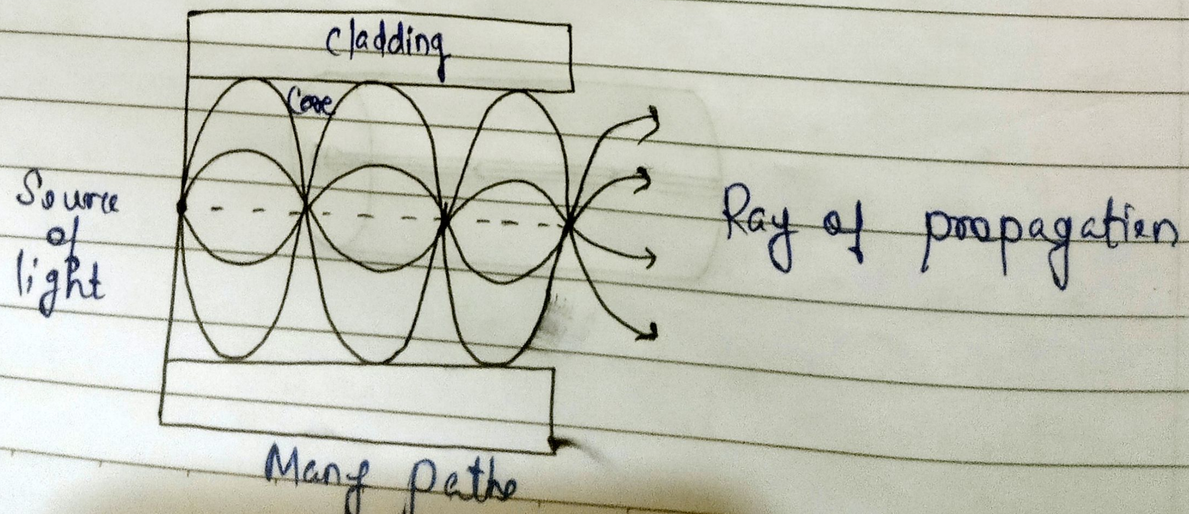


Multimode step index optical fiber

- diameter of the core of multi mode step index fiber is larger than that of single mode step index fiber.
- multiple light signals can be sent through this fiber simultaneously.
- path of light signal is zig-zag.
- used for short distance transmission of signals
- different light signals reach the other end of the fiber at different times.
- The shorter rays earlier than the longer rays.

Graded Index optical fiber

- RI of core is maximum at its center & goes on decreasing as radial distance towards cladding interface ~~decreases~~ increases.
- Due to multiple total internal reflection at various distance from axis of the core, the light signals entering the core is continuously bent towards core axis.
- light signals travel along many curved paths. Shorter rays are slower & longer rays are faster.
- light signals reach the other end of fiber at same time.



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Newton's law of cooling

When a hot body is placed in cooler surroundings, heat transfer takes place by way of conduction, convection & radiation & it cools.

Newton's law of cooling states that the loss of heat from a hot body is directly proportional to the excess of its temperature over the surroundings.

Consider a hot body at temperature θ.

let θ_0 be temperature of the surroundings.

let us assume that dQ is the quantity of heat loss by the hot body in time dt. Then rate of loss of heat i.e heat lost per second is, $\frac{dQ}{dt}$

According to Newton's law of cooling

$$\frac{dQ}{dt} \propto (\theta - \theta_0)$$

$$\therefore \frac{dQ}{dt} = k(\theta - \theta_0)$$ where k is certain constant.

let m be mass of the hot body s be its specific heat & $\frac{d\theta}{dt}$ the rate of cooling. Then we can put

$$\frac{dQ}{dt} = ms\frac{d\theta}{dt}$$

$$\frac{dQ}{dt} = k(\theta - \theta_0)$$

$$k(\theta - \theta_0) = ms\frac{d\theta}{dt}$$

$$\therefore \frac{d\theta}{dt} = \frac{k}{ms}(\theta - \theta_0)$$

For a given body, the term $\frac{k}{ms}$ is also constant.

$$\frac{d\theta}{dt} \propto (\theta - \theta_0)$$

Thus, rate of fall of temperature of a hot body is directly proportional to the excess of temperature of the body over the surroundings, provided that excess is small.