MODULE – IV

T.T.T. diagram, concept of heat treatment of steels i.e. annealing, normalizing, hardening and tempering; microstructural effects brought about by these processes and their influences on mechanical properties; factor affecting hardenability. Optical properties of Materials: Scattering, Refraction, Theory of Refraction and absorption, Atomic Theory of optical properties. Lasers, Optical fibres- Principle, structure, application of optical fibres.

MODULE - IV

Concept of Heat treatment of Steel :-

↳ Steels are the most versatile engineering materials because these are cheap, easily available, have good machinability, weldability, their properties can be enhanced by addition of alloying elements etc.

↳ Steels can be given any proper heat treatments to obtain any desired combination of strength and ductility within a very wide range.

↳ Heat treatment can be defined as "a combination of heating and cooling operations, timed and applied to a metal or alloy in the solid state in a way that will produce desired properties."

↳ Different heat treatment process for steel are annealing, normalising, quenching or hardening, tempering, different surface modification heat treatment processes are also there.

Annealing

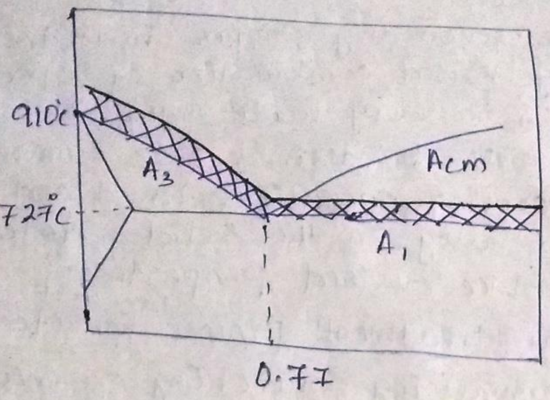
Annealing, in general refers to heating the material to a predetermined temp., soaking at this temp. & then cooling it slowly, normally in a furnace by switching it off.

The aims of annealing the steel could be varying, & that is why there are a no. of annealing heat treatments. The main aims of annealing and as a consequence the derived names of the type of annealing are—

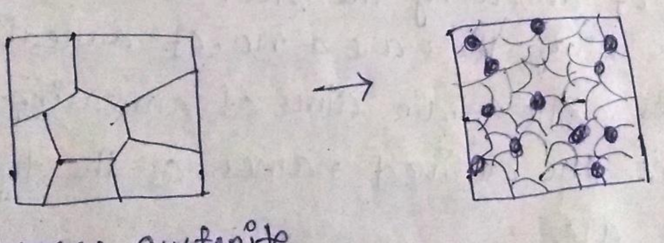
1. Full annealing:

It consists of heating the steel to a temp. above upper critical temp., soaking there for sufficient time to obtain homogeneous austenite and then, left to cool in the furnace by switching it of.

For hypoeutectoid and eutectoid steel,
$= Ac_3 + (20 - 40°C)$
For hypereutectoid steel,
$= Ac_1 + (20 - 40°C)$



Microstructure : At A_3 for hypoeutectoid steel, fine grains of austenite which on slow cooling results in coarse grains of ferrite and pearlite.
For hypereutectoid fine grains of austenite with spheroidised Fe_3C which on slow cooling through A_1 produces fine grains of pearlite & spheroidised cementite.



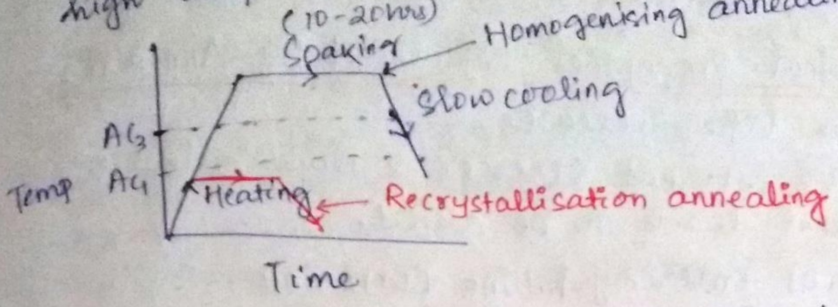
Coarse austenite

Fine grained ferrite + Pearlite

Aim :- i) Improve mechanical properties of cast or hot worked steels by refining the grain size.
ii) To soften the steel
iii) To relieve internal stress
iv) To improve machinability
v) Reduces defects like sulphide inclusions

2. Homogenising Annealing :-

The process is heating, soaking and hotworking. This is so as diffusion of carbon is very fast at high temp.



Aim: To make uniform composition i.e. to remove chemical heterogeneity.

Microstructure: Grain coarsening of austenite. But it is not required, thus steels after such heat treatment undergo normalising or full annealing.

3. Recrystallisation Annealing :-

It is similar to sub-critical annealing. Steel heated below Ac_1 temp (650-680°C) and latercooled. It restores ductility.

Recrystallisation annealing consists of heating the cold worked steel above its recrystallisation temp, soaking at this temp. & then cooling there after. Normally $T_r = (0.3-0.5)T_{mp}$

Aim: To restore ductility, refine coarse grains, improve electrical and magnetic properties.

Microstructure: Strain free, equi axed grains of fine ferrite.

4. Spheroidisation Annealing :-

Heating of steel ($C > 0.3\%$) just below Ac_1 temp., holding at this temp. for a very long period followed by slow cooling.

Aim: Maximum softness, ductility, highest machinability, minimum hardness.

Microstructure: spheroidal pearlite or globular form of carbides in steel.

Mechanical properties influenced by Annealing

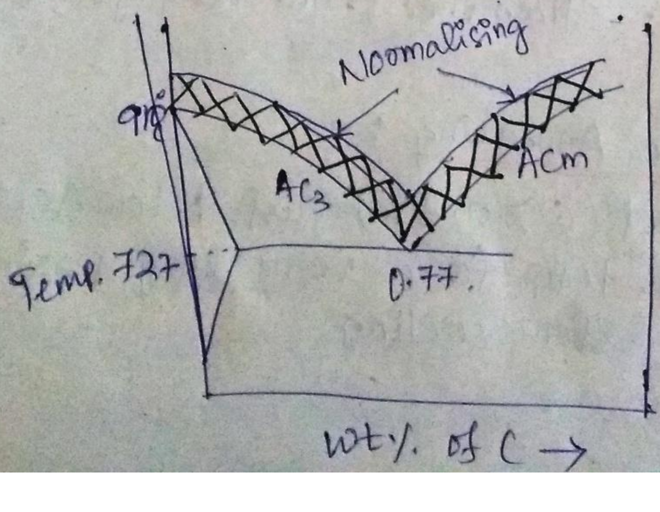
i. Fatigue life increases.
ii. Relieve internal stresses & thus allow higher external loads to be allied.
iii. Prevent intercrystalline corrosion.
iv. Increase impact resistance
v. Ductility increases.
vi. Reduce hardness
vii. Shaping, stamping or forming occurs.
viii. Enhances electrical conductivity.

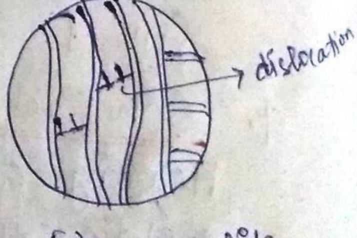
Normalising

It is the process of heating the steel to single phase austenitic region to get homogeneous austenite by soaking and allowing to cool freely in air.
The austenitising temp. range for various steels are

$T_{normalising} = AC_3 + (40-60^\circ C)$ for hypoeutectoid and eutectoid steel

$= ACm + (30-50^\circ C)$ for hypereutectoid steel.





Fine pearlite

Though similar to annealing, normalising is done to obtain ferrite / Fe_3C and lamellar pearlite. Process variables are higher temp. of austenitising (to prepare more homogeneous austenite) and air cooling being faster than furnace cooling helps to supercool austenite, much below A1 temp.

Aim of normalising :-

1. To refine coarse grains of steel castings, forgings etc.
2. To improve mechanical properties of plain carbon steel.
3. To eliminate or reduce microstructural irregularities
4. To increase machinability of low carbon steel.
5. To eliminate or break coarse cementite network in hypereutectoid steels.
6. Grain refinement of structure prior to hardening of steels.

Microstructure

1. Finer proeutectoid ferrite grains
2. Much finer pearlite (interlamellar spacing is reduced)
3. Finer pearlite grains
4. Amount of proeutectoid ferrite is reduced. In case of hypereutectoid steels, proeutectoid cementite is less than annealing.

Mechanical Properties influenced by Normalising

1. Higher hardness, strength with slightly decrease ductility.
2. Machinability is better of low carbon steel.
3. Intricate shaped or critical parts, or parts not to have internal stress can be annealed.
4. Improve toughness

Comparision Between Annealing And Normalising

Full-Annealing	Normalising
1. Lower hardness, strength with high ductility.	1. Higher hardness, strength which increase with increasing carbon content.
2. Internal stresses are nominal.	2. Internal stresses are more due to faster air cooling.
3. Grain size coarser.	3. Grain size obtained is fine.
4. Microstructure is bit less uniform.	4. Microstructure obtained is more uniform and dispersed.
5. It is expensive and takes longer time.	5. It is cheaper and takes much less time.
6. Machinability is better of 0.3-0.4% carbon steel.	6. Machinability is better of low carbon steel.
7. It is less effective in removing chemical heterogenity.	7. It removes heterogenity of microstructure.
8. It cannot break thick cementite network.	8. Brittle network of cementite can be broken in hypereutectoid steels.
9. Normalising is preferred over annealing. But intricate shaped, critical parts not to have internal stress at all are annealed.	9. Normalising is preferred for better mechanical property.

Hardening

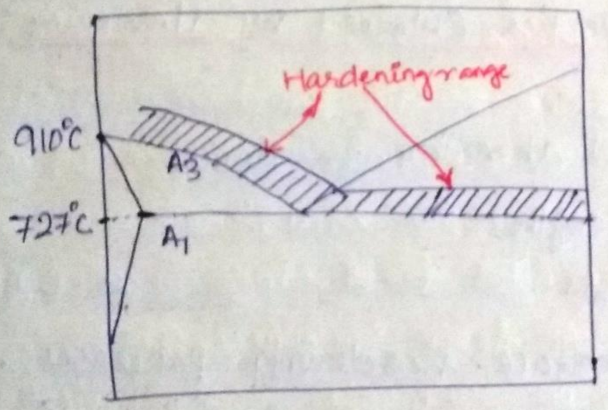
↳ It is the process of heating the steel to proper austenitising temp., soaking at this temp. to get a fine grained and homogeneous austenite and then cooling the steel at a rate faster than its critical cooling rate. Austenite transforms to <u>martensite</u>, and steel becomes hard.

Q: What is martensite ??

A: Martensite is a supersaturated solid solution of carbon in α-iron. Martensitic transformation is a diffusionless transformation, has same composition as the parent austenite. It has <u>body centred tetragonal</u> (BCT) crystal structure. It's morphology is <u>lath type</u> (in low and medium carbon steel) and <u>plate or acicular or lenticular type</u> (found in high carbon steel).

↳ Temp. for hardening, For hypoeutectoid steels = $Ac_3 + (20\text{-}40°C)$

For hypereutectoid or eutectoid steel = $Ac_1 + (20\text{-}40°C)$



Carbon Wt%

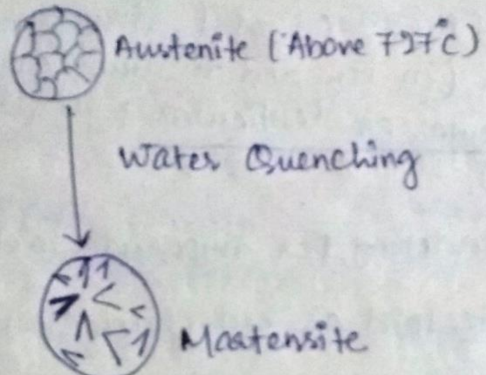
↳ The rapid cooling is obtained by bringing in contact the hot surface of the object with some cooler material which could be gaseous, liquid or solid. This operation is called <u>quenching</u>. Quenching may be done by jet of air, water, or other liquids; or by immersing in liquid such as brine, water, oils, polymer, salt bath etc.

Objectives of Hardening :-

1. Induce high hardness. Cutting ability of a tool is proportional to it's hardness.
2. Many machine parts & tools are hardened to induce high wear resistance. Higher the hardness, higher is the wear and abrasion resistance.
3. Develope high yield strength with good toughness and ductility to bear higher working stresses.

Microstructure :

Retained austenite + Martensite



Mechanical Properties Obtained by Hardening :-

1. High hardness
2. Good wear and abrasion resistance
3. High yield strength
4. Good toughness

↳ Some other surface hardening processes such as carburizing, nitriding, cyanding, induction and flame hardening can also carried out. These are the surface modification processes which are very much useful for automotive industries.

Tempering

- Tempering is the process of heating the hardened steel to a temp. maximum up to A_1 temp. soaking at this temp. and then cooling normally very slowly. Tempering temp. used depending up on properties required by the carbon tools.
- Tempering is the important heat treatment process to be carried out after hardening. After hardening steel have martensitic structure with some retained austenite (RA). Presence of RA decreases hardness of hardened steel or on later service it may transform to bainite or martensite. Hence to remove retained austenite tempering treatment is provided.

Aims of Tempering:

Tempering of steels is done with one or more of the following aims.

1. To relieve quenching stresses developed during hardening.
2. To restore ductility and toughness with decrease in hardness and strength.
3. To improve dimensional stability by decomposing retained austenite.
4. To improve magnetic properties by transforming non-magnetic retained austenite.

Stages of Tempering:

As temp. raised, tempering of carbon steels occurs in four distinct but overlapping stages.

I. First stage of tempering

This tempering can be carried out ~~at~~ up to 200°C. $C > 0.2\%$ containing steel decomposes martensite in to tetragonality martensite. i.e. tempered martensite and ϵ - carbide $Fe_{2.4}C$ precipitates. This precipitation enhances hardness.

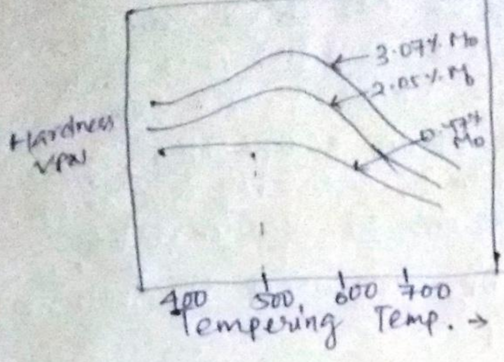
II. Second stage of Tempering :
It is carried out at 200-300°C. Here retained austenite decomposes and transforms in to bainite. There takes place slight increase in volume.

III. Third stage of tempering:
It is carried out at 200-350°C. Here martensite completely loss it's tetragonality, ε- carbide dissolves and cementite rod formed. Structure is ferrite and cementite. It contracts the volume.

IV. Fourth stage of tempering :
Temp. maintained here is 350-700°C. Recovery & Recrystallization of ferrite, coarsening and spheroidisation of cementite occur.

But in industrial practice it is of three stages.
i/ Low temp. tempering (1-2 hrs in up to 250°C)
ii/ Medium temp. tempering (350-500°C)
iii/ High temp. tempering (500-650°C)

Q: What is secondary hardening ??
A: ↳ Secondary hardening mostly found in alloy steel's tempering. Alloy steels have addition of alloying elements such as ferrite stabilizers and carbide forming elements. At first stage it will not effect but when temp. increases above 500°C carbide forming elements form their own carbides to replace coarse cementite particles. This is known as secondary hardening.
↳ It enhances hardness with improved toughness. This increase in hardness is called secondary hardness.

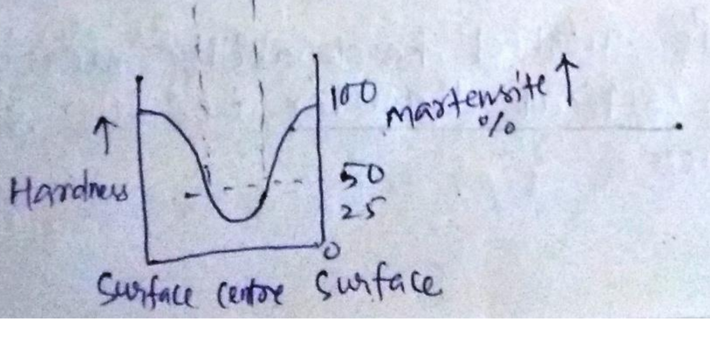


Hardenability

Hardenability can be defined as the property of the steels which determines the depth and distribution of hardness produced by quenching. It is the capacity of steel to develop a desired degree of hardness usually measured in terms of depth of penetration.

Hardness is defined as resistance to indentation. The hardness of quenched steel generally means hardness of 100% martensitic structure, which is basically a function of carbon content even in most alloy steels. Hardenability is depth (from surface) which contains 50% martensite and 50% other products.

Lets take an example of 5cm diameter cylindrical steel pipe hardened by water quenching and fracturing at half of it's length.



↳ The outer case have martensitic structure which is a brittle one, hence it has high hardness and undergo brittle fracture. But the core has non-martensitic structure shows ductile fracture.

↳ Hardenability depends up on composition, grain size, Nature of coolant, geometry & size of component and criterion of hardenability.

↳ Hardenability can be measured by two ways.

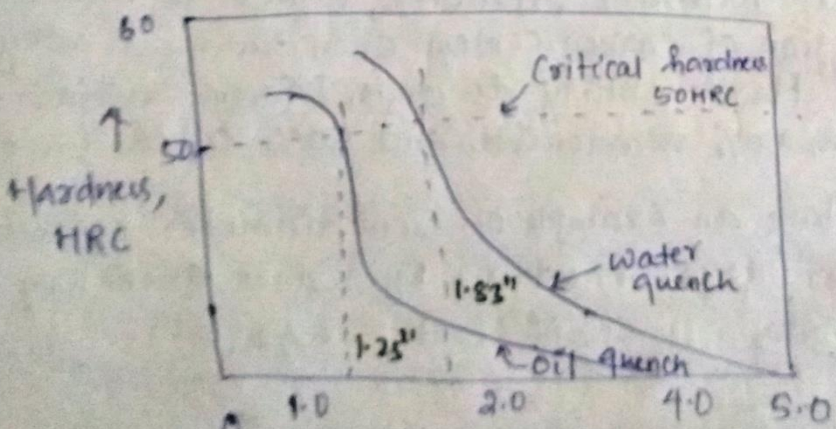
1. Grossman's method
2. Jominy' End-Quench test.

1. Grossman's Method

Short note

A large no. of cylindrical samples of different diameters of same steel austenized and quenched in same coolant. Then those will be cut to half lengths, hardness measured at centres and plotted against diameter of bar.

It is found that rapid fall in hardness occur where it has 50% martensite structure.



In Grossman's method hardenability measured in terms of critical diameter, i.e. the steepest fall in hardness.

Critical diameter (D_c) can be defined as the diameter of bar up to which it hardens. But it varies with different quenching media. It depends up on severity of quench. Therefore now Ideal Critical diameter (D_I) came in to existance, which can be defined as the diameter for which the unhardened core just disappears, if the bar is subjected to ideal quench. It is the diameter of bar which when quenched in ideal quench 50% martensite in it's core.

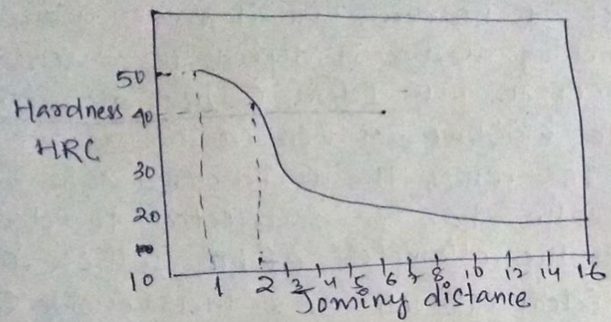
2. Jominy End Quench Test short note

↳ Grossman's method is laborious, difficult and expensive one. Jominy End quench test is simple and easy one, hence universally accepted.

↳ The normalised steel is machined to 4" length & 1" dia. It is austenised for 30 minutes at 22-23C above it's AC_3 temp. A stream of water is then directed against the bottom of specimen for not less than 10 minutes. Thus quenching consists of cooling one end of Jominy bar a jet of water i.e. cooling takes place by unidirectional flow of heat towards the quenched end.

↳ The hardness of specimen is measured on Rockwell 'C' scale at an interval of 1/16" along length starting from water quenched end. The hardness then plotted against the distance from as quenched end of Jominy piece.

↳ As cooling rate decreases with increasing distance, increased amount of nonmartensitic products are formed. Hence gradually hardness decreases. This curve is known as 'Jominy hardenability Curve'.



One Jominy distance = $\frac{1}{16}''$

The point of inflection in this curve corresponds to 50% martensite and is a measure of hardenability of steel.

Factors Affecting Hardenability

The following factors affect hardenability.

1. **Grain size:**
If austenite grain size is large, then grain boundary area is less. The probability of nucleation of ferrite & pearlite decreases. It shifts 'S' curve to right. This method of increasing hardenability is avoided as coarse grains are not preferrable.

2. **Carbon content:**
Carbon content increases hardenability but after 0.77% it decreases because undissolved proeutectoid cementite acts as nuclei for pearlitic transformation.

3. **Alloying elements:**
Most alloying elements (except Co) shift TTT curve towards right to increase hardenability of steel. The presence of undissolved alloy carbides not only deplets γ of alloying elements as well as

Carbon which would have increase hardenability. Boron is most effective in increasing hardenability.

4. Severity of Quench:

Critical diameter increases as severity of quench increases to become max^m ideal critical diameter (DI), when coolant is an ideal quench.

$$\text{Severity of quench} = \frac{\text{Heat transfer co-efficient}}{\text{Thermal conductivity}}$$

5. Mass effect:

Max^m hardness obtained on surface of bar of small dia & decreases as diameter increases. The centre hardness continues to drop as bar dia increases. Hardenability is measured in terms of depth of penetration of hardness.

T.T.T. Diagram short note

↳ Time - Temperature - Transformation curve is known as TTT curve which gives us idea about transformation of austenite as a function of time at constant temp. Hence it is alsoknown as isothermal transformation (IT) diagram. These curves have 'C' or 'S' shape in plain carbon and low alloy steels. Each steel composition has it's own different curve.

↳ TTT curve came in to existance because of some limitations found in phase diagrams. Phase diagram did not gave us idea about phases formation due to sharp cooling and their properties.

↳ TTT curve formed by doing no. of transformations formation of phases will our at what time and end of transformation time noted and collectively joined, which gave 'C' or 'S' shape.

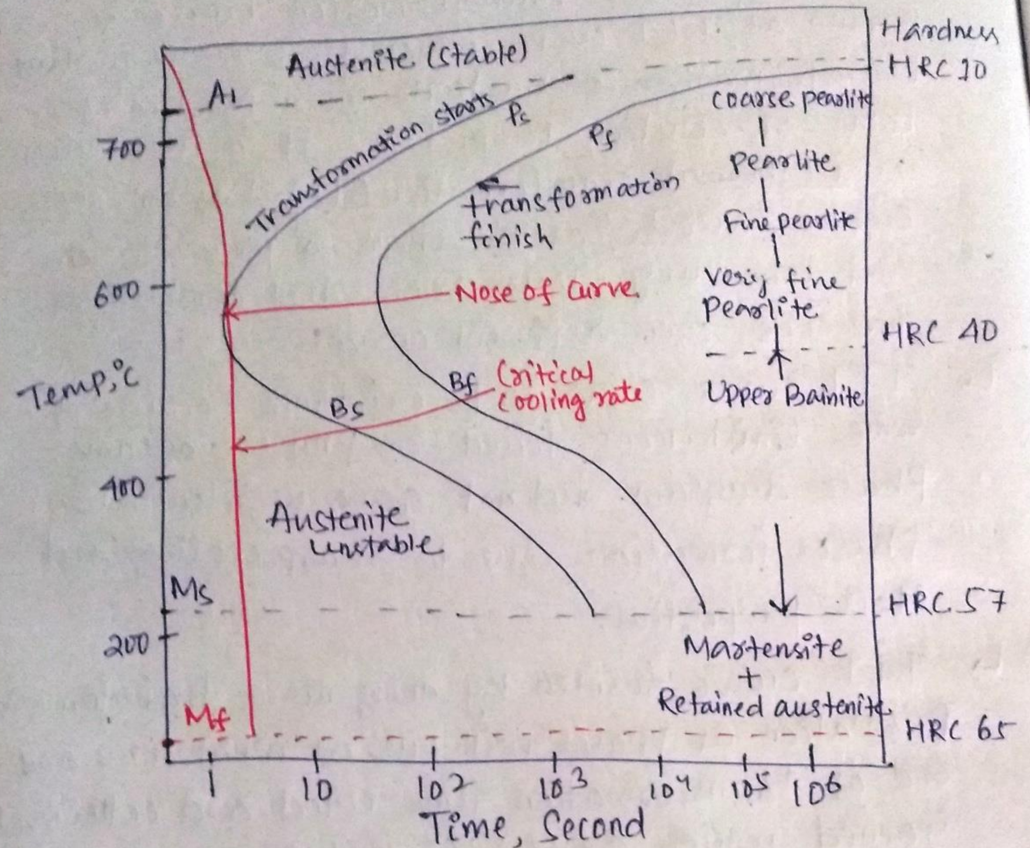
↳ Here incubation period is the period in which transformation does not proceed because enough diffusion has not taken place in austenite for the transformation to start. The region of fastest transformation is called nose of curve. Here maximum transformation occur.

↳ A TTT diagram illustrates three different types of transformation products.

i) Pearlitic range (High temp. transformation)

ii) Bainitic range (Intermediate temp. transformation)

iii) Martensitic range (Low temp. transformation)



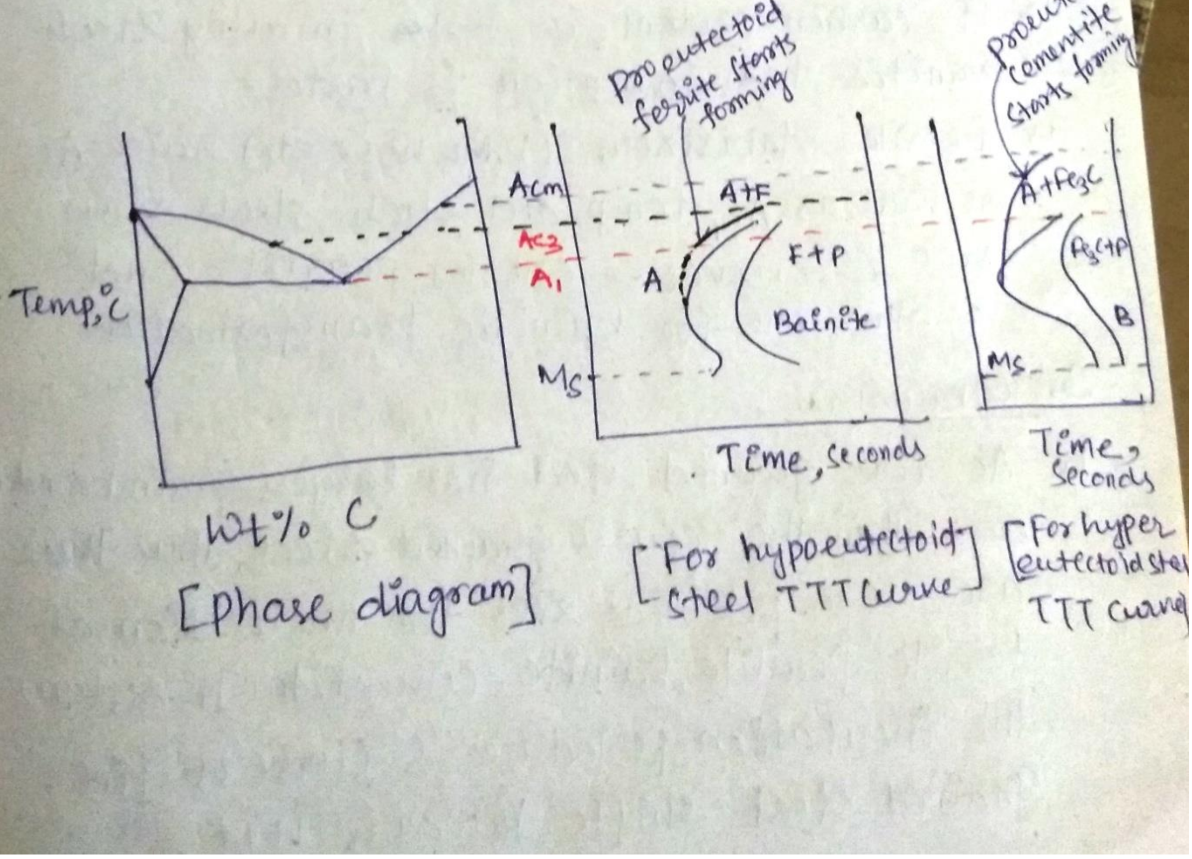
[TTT Curve for eutectoid steel]

↳ Just below A_1 temp. coarse pearlite forms and as temp. of transformation is lowered, fine and finer pearlite forms having hardness of HRC 40. The lower the transformation temp., free energy difference betn old and new phase increases i.e. the driving force for transformation

↳ Near knee of the curve both pearlite and bainite can form. Below knee and above martensite start temp. is the region for bainite, which is the isothermal product of austenite. Bainite is the aggregate of ferrite and carbide. Upper bainite of feathery structure formed at upper temp. range (550 - 400°C) whereas lower bainite of acicular structure forms at lower temp. range i.e. (400 - 250°C).

↳ When austenite supercooled to M_s temp., driving force for austenite transformed to martensite becomes very large. Martensite acquires a distorted form of BCC due to more carbon presence in solid solution. It has body centred tetragonal (BCT) structure. This distortion causes high hardness of martensite.

↳ Imp Critical cooling rate is defined as the slowest cooling rate which produces fully martensitic structure.



Factors Affecting TTT Curve :

1. Carbon Content :-

↳ Carbon increases stability of austenite and amount of free ferrite decreases as carbon amount increases up to 0.77 %. As ferrite is the nucleating phase for pearlite in hypoeutectoid steel nose of S-curve shifts towards right

↳ But above 0.77 % in hypereutectoid range cementite acts as nuclei for pearlitic transformation, so nose will shift to left.

2. Alloying elements :-

↳ All alloying elements except Co shift 'S' curve to right both in pealitic and bainite regions.

↳ Austenite stabilizers (Ni, Mn, C etc) stabilize austenite, thus shift the curve to right.

↳ If carbon content is less in alloy steels bainitic transformation is faster.

↳ Ferrite stabilizers (V, Mo, W, Cr etc) raise A_{C_3} as well as A_{C_1} temp. and such steels show two 'C' curves — one for pearlitic and another one for bainitic transformation.

3. Grainsize :-

↳ As fine grained steel has larger grain boundary area than the coarse grained steel, thus there are more potential sites for nucleation of ferrite, pearlite, bainite, cementite. It reduces the incubation period i.e. 'S' curve of fine grained steel shifts towards left.

Applications of TTT diagrams :-

1. <u>Martempering</u> :-

↳ It consists of quenching the heated steel above M_s, holding for sufficient time to uniform the temp. and then air cooling through M_s to room temp. to obtain martensite simultaneously. Tempering will be carried out as a second stage.

↳ Microstructure : Martensite.

2. <u>Austempering</u> :-

↳ It consists of quenching austenised steel above M_s temp. (300-400°c), then held at this temp. to let austenite transform completely to lower bainite. Tempering is not required here ;

↳ Microstructure : Lower bainite

↳ It's advantages :
Improve ductility at same hardness, free from distortion, cracks, high impact strength, endurance limit.

3. <u>Patenting</u> :-

↳ It consists of austenizing steel in a continuous furnace to temp. 150-200°c above Ac_3 then cooled rapidly in & holding in a lead bath, maintained at a temp. of 450-550°c for sufficient time for austenite to completely transform to fine pearlite.

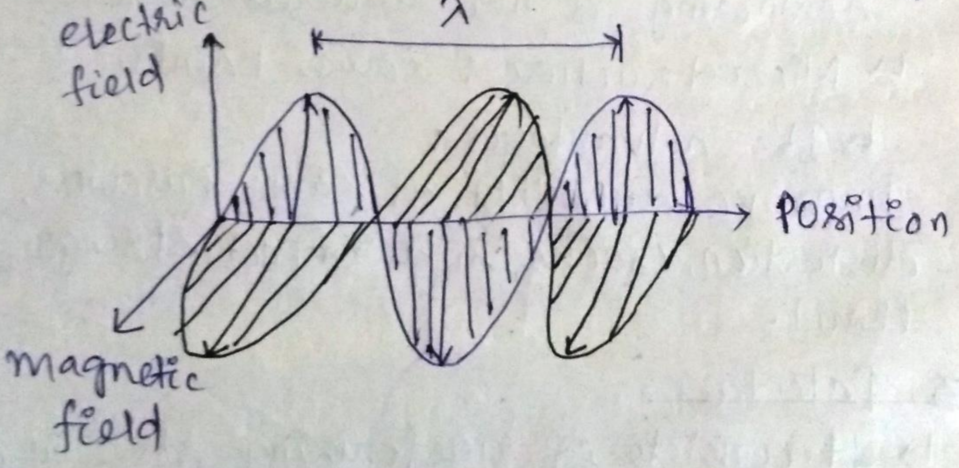
↳ Microstructure : Fine pearlite

↳ Advantages : High strength and toughness in twisting and bending.

Most industrial heat treatments are carried out by continuous cooling of steels. So CCT (continuous cooling Transformation) also used but it cannot predict bainite.

Optical Properties of Materials :

- Optical Property is meant for a material's response to exposure to electromagnetic radiation and in particular to visible light. Electro-magnetic radiation is considered to be wave like, consisting of electric and magnetic field components that are perpendicular to each other and also in direction of propagation.



- The electromagnetic spectrum of radiation spans the wide range from γ-rays having wavelength (λ) on 10^{-12}m through x-rays, ultraviolet visible, infrared and finally radio waves with wavelengths as long as 10^{5} meter.

↳ All electromagnetic radiation traverses a vacuum at same velocity, that of light — 3×10^8 m/s. This velocity (c) is related to electric permittivity of vacuum ϵ_0 & magnetic permittivity of vacuum (μ_0)

$$\boxed{c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}}$$

and $c = \lambda \nu$ ν = frequency

↳. Energy packets (E) are called photons.

$$E = h\nu = h\frac{c}{\lambda}$$

h = Planck's const. $= 6.63 \times 10^{-34}$ JS

↳ When light proceeds from one medium into another several things may happen. Some of light radiation may transmit, absorbed or reflected at the interface between two media.

∴ Intensity of incident beam = Intensity of transmitted beam + Intensity of absorbed beam + Intensity of reflected beam

$$\Rightarrow I_0 = I_T + I_A + I_R$$

Reflection

When light radiation passes from one medium into another having different index of refraction, some of light is scattered at interface between two media even if both are transparent. The reflectivity R represents fraction of incident light i.e. reflected at interface, or

$$R = \frac{I_R}{I_0}$$

When light is normal (or perpendicular) to interface, then, $R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$

n_1, n_2 are indices of reflection of two media.

When light is not normal to interface, R will depend up on angle of incidence. When light is transmitted from vacuum or air into a solid s, then

$$R = \left(\frac{n_s - 1}{n_s + 1}\right)^2$$

Scattering

↳ Scattering is a general phenomena of physical process where some forms of radiation such as light, sound, or moving particles are forced to deviate from a straight line trajectory by one or more localized nonuniformities in the medium through which they pass.

↳ Reflections which undergo scattering are often called diffuse reflections & unscattered reflection are called specular reflections.

↳ The types of nonuniformities which cause scattering are inclusions, surface roughness, density fluctuation in liquids etc.

↳ Same areas where scattering theory is significant are radar sensing, medical ultrasound, semiconductor wafer inspection, free space communication, acoustic filing, computer generated images etc.

- When radiation is commonly scattered by one localized scattering centre, this is called single scattering. It is very common that scattering centres are grouped together and in those cases radiation may scatter many times, which is known as multiple scattering. Multiple scattering can sometimes have somewhat random outcomes, particularly with coherent radiation.

Theory of Refraction:

- Light that is transmitted in to the interior of transparent materials experience a decrease in velocity and as a result is bent at interface; this phenomenon is termed refraction.
- The index of refraction (n) of a material is defined as the ratio of the velocity in a vacuum 'c' to the velocity in medium v, or

$$\boxed{n = \frac{c}{v}}$$

- The magnitude of n will depend on the wave-length of the light.

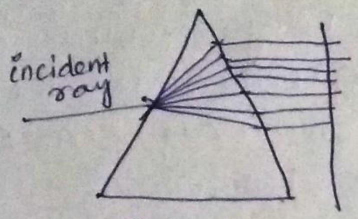
$$v = \frac{1}{\sqrt{\epsilon \mu}}$$

$$n = \frac{c}{v} = \frac{\sqrt{\epsilon \mu}}{\sqrt{\epsilon_0 \mu_0}} = \sqrt{\epsilon_r \mu_r}$$

where ϵ_r and μ_r are the dielectric const. and relative magnetic permeability respectively.

For most substances $\mu_r \approx 1$.

$\therefore n = \sqrt{\epsilon_r}$ (For transparent material)



Prism

Refractive index not only affect optical path of light but also incident light i.e. reflected by surface.

Retardation of electronic radiation in a medium results from electronic polarization. The size of constituent atoms or ions has a considerable influence on magnitude of this effect generally larger than atom/ion, greater will be electronic polarization, slower the velocity and greater the refractive index.

Q: Can refractive index be less than 1?? 2 marks

A: NO, Because incident ray moves faster in vacuum rather than in any other medium.

Exceptional case: May be less than 1 in earth ionosphere.

Theory of Absorption:

Nonmetallic materials may be opaque or trans-parent to visible light and if transparent they often appeared coloured. In principle light can be absorbed by two mechanisms.

i. Electronic polarization: This principle carried out when light frequencies in the vicinity of the relaxation frequency of constituent atoms.

ii. Valence bond – conduction bond transition: This depends up on electron energy band structure for semiconductors & insulators.

↳ Absorption of a photon of light may occur by the promotion or excitation of an e^- from nearly filled valence band, across the band gap & in to an empty state within conduction band.

Free e^-s in conduction band and hole in valence band are created. Again energy of excitation $\Delta E = h\nu$, where ν = absorbed photon frequency.

This excitation with accompanying absorption can take place only if photon energy is greater than that of band gap energy (E_g) i.e.

$$h\nu > E_g$$

$$\text{or } h\frac{c}{\lambda} > E_g \quad \text{(In terms of wave length)}$$

Visible light range 0.4 – 0.7 μm.

For minimum wave length i.e. $\lambda = 0.4\ \mu m$

$$\therefore E_g(\max) = \frac{hc}{\lambda} = \frac{(4.13\times10^{-15}\,eV.s)(3.0\times10^{8}\,m/s)}{4\times10^{-7}\,m}$$

$= 3.1\ eV$

For max^m wavelength i.e. $\lambda = 0.7\ \mu m$

$$E_g(min) = \frac{hc}{\lambda} = \frac{(4.13\times10^{-15}\ eV.s)(3.0\times10^{8}\ m/s)}{7\times10^{-7}\ m}$$

$= 1.8\ eV$

This results show that only a visible spectrum is absorbed by materials having band gap energies in bet^n 1.8 – 3.1 eV. Then materials are opaque and appear coloured.

↳ Every nonmetallic material becomes opaque of some certain wavelength which depends on a magnitude of it's E_g value.

Ex : Diamond have $E_g = 5.6\ eV$ & $\lambda < 0.22\ \mu m$.

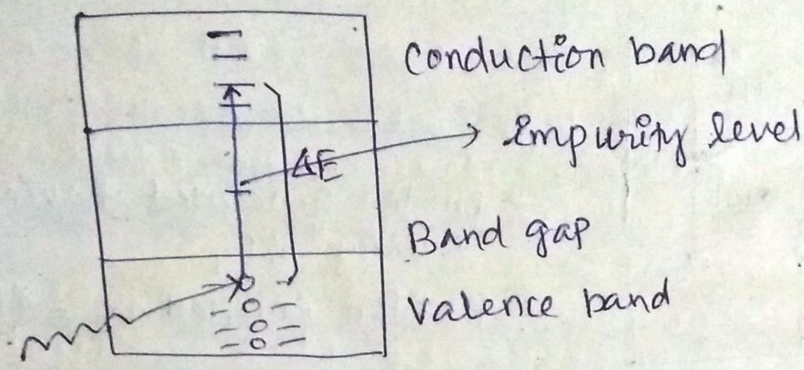
Absorption in Dielectrics :

A dielectric material is an electrical insulator that can be polarized by an applied electric field. when a dielectric placed in an electric field, electric charges do not flow through the material and they do in an electrical conductor but only slightly shift from their average equilibrium position causing dielectric polarization.

Light radiation can also interact with dielectric solids having wide band gaps, involving other than valence – conduction band electron transitions.

If impurity or other electrically active defect are present, electron levels within the bandgap may be introduced such as donor and acceptor levels, except that they lie closer to centre of band gap.

Light radiation of specific wavelengths may be emitted as a result of electron transitions involve energy levels within a gap.



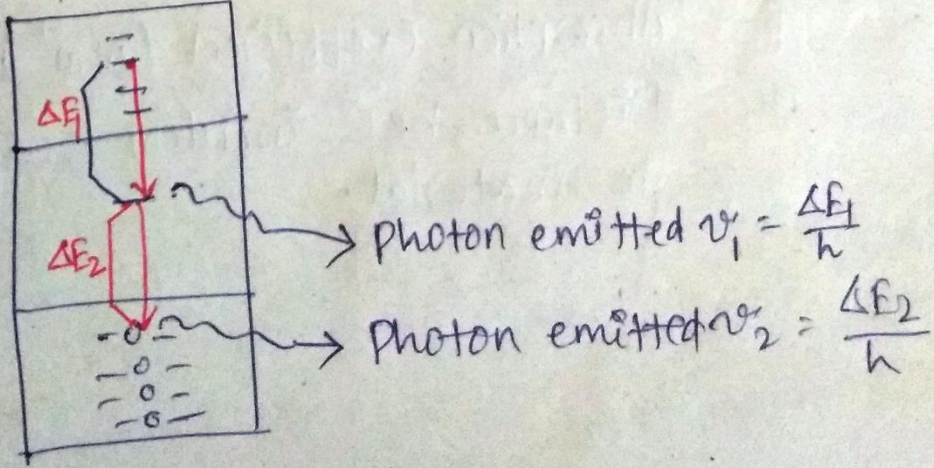
photon
absorbed

When incident ray provided electromagnetic energy was absorbed but electron execation must be dissipated by direct e^- & hole recombination.

electron + hole → energy (ΔE)

Multiple step electron transition may occur.

i) Emission of two photons.



Atomic Theory of Optical Properties:

The optical phenomena that occur within solid materials involve interactions between the electro-magnetic radiation and atoms, ions, and/or e's. Two of the most important of these interactions are (1) electronic polarization and (2) electron energy transitions.

1. Electronic Polarization :-

One component of an electromagnetic wave is simply a rapidly fluctuating electric field. For visible range of frequencies, this electric field interacts with the electron cloud surrounding each atom within it's path in such a way as to induce electronic polarization, or to shift the electron cloud relative to the nucleus of the atom with each change in direction of electric field component.

↳ Two sequence of this polarization are

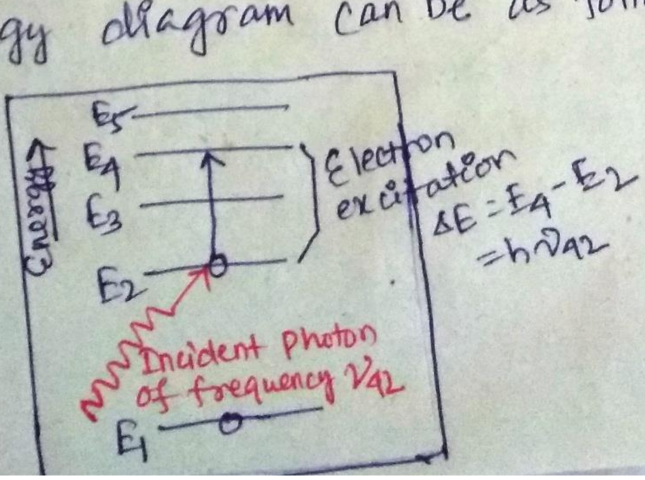
i) Some of the radiation energy may be absorbed.

ii) Light waves are retarded in velocity as they pass through the medium. (Refraction)

2. Electron Transitions :-

The absorption and emission of electromagnetic radiation may involve electron transitions from one energy state to another.

Lets consider an isolated atom, the electron energy diagram can be as follows.



An electron may be excited from an occupied state at energy E_2 to a vacant and higher lying one, denoted E_4, by absorption of a Photon of energy. The change in energy experienced by e^-, ΔE, depends on radiation frequency. $\boxed{\Delta E = h\nu}$

Where h = Planck's constant

↳ First since the energy states for the atom are discrete, only specific ΔE's exist bet^n energy levels. Thus only photons of frequency corresponding to possible ΔE's for the atom can be absorbed by electron transition.

↳ Secondly, a stimulated electron cannot remain in an excited state indefinitely; after a short time, it falls or decays back into it's ground state, or unexpected level, with a reemission of electromagnetic radiation.

Several decay paths are possible, and there must be conservation of energy for absorption & emission electron transitions.

Applications of Optical phenomena :

Interaction of electromagnetic radiation with solid body can be helpful for various applications.

1. Luminescence : It is the process where a material absorbs energy and then immediately emits visible radiation. This phenomena can be used in fluorescent lamps, CRT, plasma video screens, white LEDs etc.

2. Photo-conductivity : Bombardment of semiconductors by photons, with energy equal to greater than the band gap, may result in creation of electron-hole pairs that can be used to generate current. This process is called photoconductivity.

↳ This phenomena is utilised in photographic light meters, CdS is commonly used for detection of visible light as in light meters, solar cell.

3. LASER 10 or 16 marks

↳ LASER is defined as Light Amplification by Stimulated Emission of Radiation. A Laser is a device that emits light through a process of optical amplification based on stimulated emission of electromagnetic radiation.

↳ All the radiative electron transitions are spontaneous i.e. an e^- falls from a high energy state to a lower one without any external provocation. These transition events occur independently of one another and at random times, producing radiation i.e. incoherent, light waves are out of phase with one another.

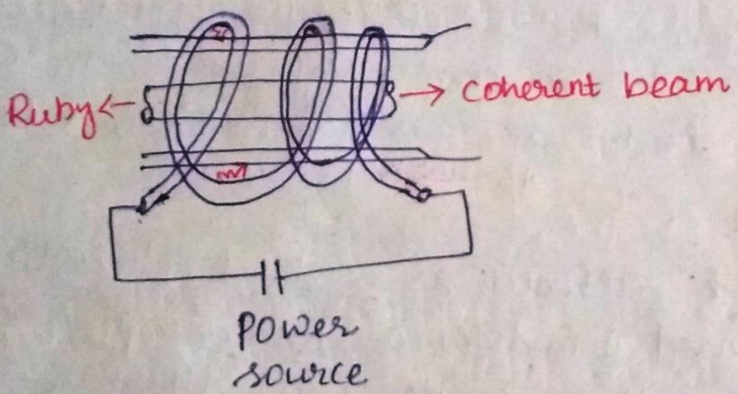
↳ With laser coherent light is generated by electron transitions initiated by an external stimulus.

Principles of Operation

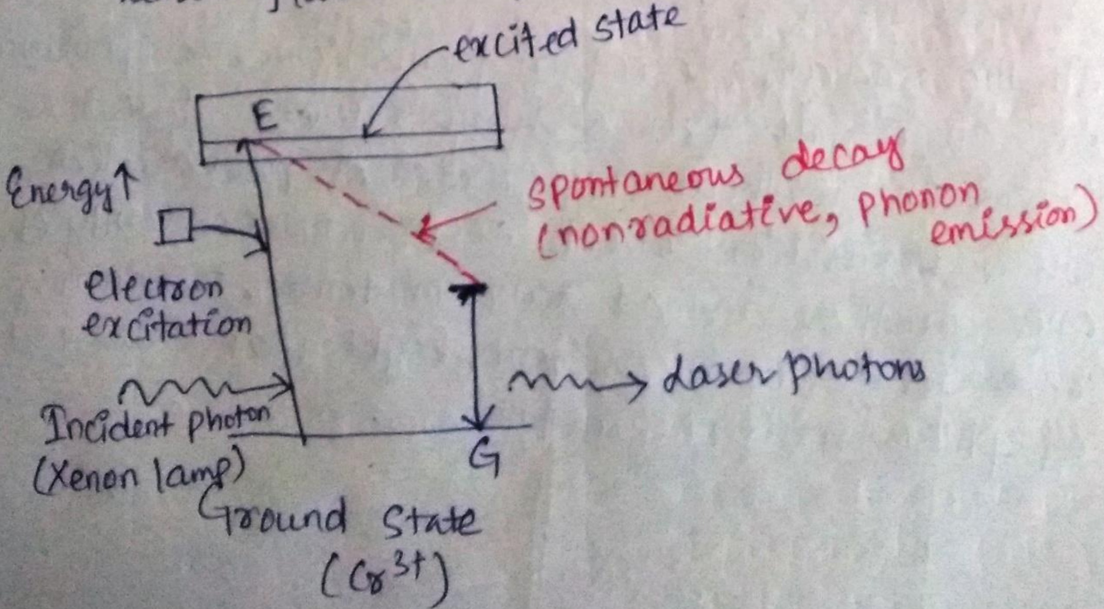
[Using a solid state Ruby laser]

Ruby is a single crystal of Al_2O_3 with which 0.05% Cr^{3+} ions added.

The ruby laser is in the form of rod, the ends of which are flat, parallel & highly polished. Both ends are silvered such that one is totally reflecting and other ~~one~~ is partially transmitting.



The ruby is illuminated with a light from xenon flash lamp.

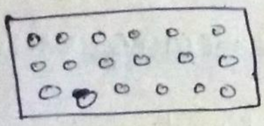


Before exposure Cr^{3+} ions are in their ground state, i.e. e^-s fill lowest energy levels. Photons of xenon wave length 0.56μm from xenon lamp excite e^-s from Cr^{3+} ions into higher energy states. These e^-s can decay back into their ground state by two different paths.

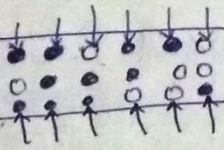
1. Electrons fall back directly without emitting photon.
2. Electrons decay in to metastable intermediate state and then come to ground state.

Stimulated emission:

• → excited Cr atom
o → Cr atom in ground stat

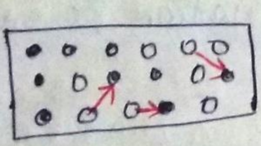


[Cr^{3+} ions before excitation]



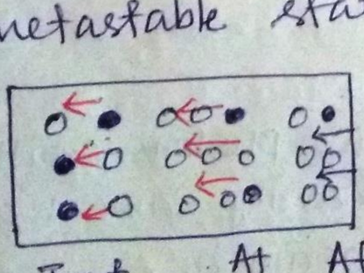
[Electrons in some Cr^{3+} ions are excited in to higher energy state by xenon light flash]

Large no. of e^- acquire metastable here.



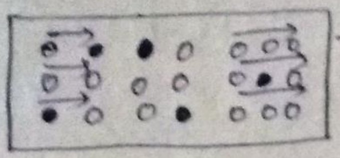
[Emission from metastable state]

Initial spontaneous photon emission by a few of these e^- is the stimulus that triggers an avalnche of emission from the remaining metastable state.



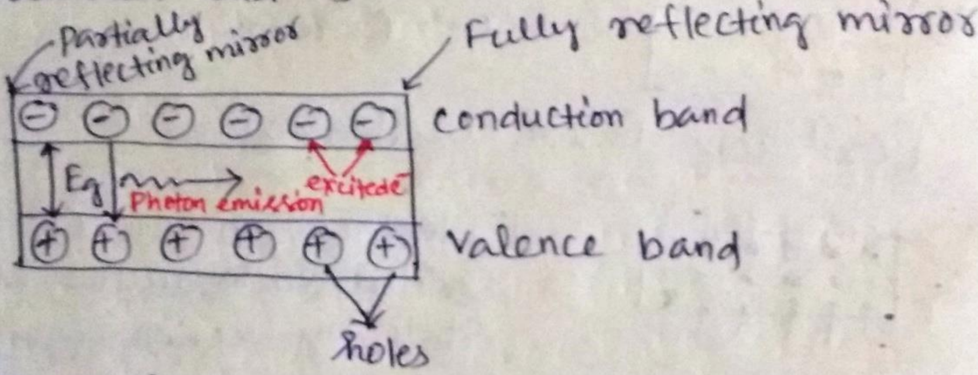
Just before next reflection | At mid crystal | After reflection

Up on reflection from silver ends, the photons continue and stimulate emissions as they traverse the rod length.

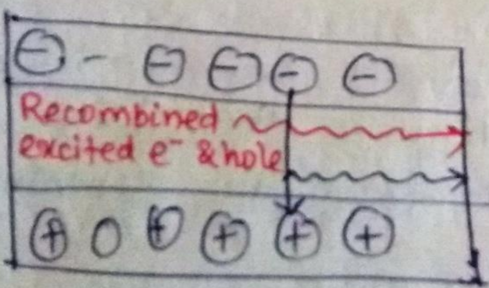


[Coherent & intense beam is finally emitted through the partially silvered end.]

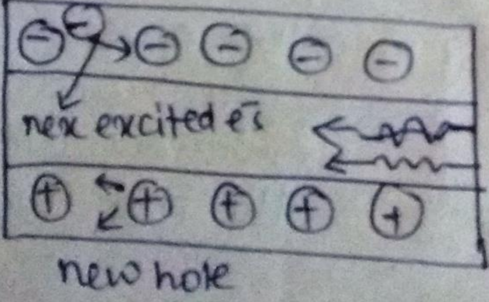
The light beam repeatedly travels back and forth along the rod length, & it's intensity increases as more emissions are stimulated. Ultimately high intensity, coherent and highly collimated laser light beam of short duration is transmitted through the partially silvered end of rod.



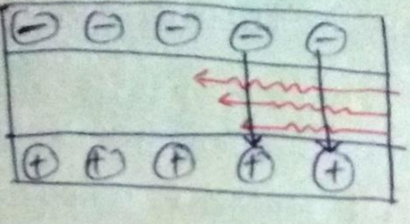
One excited e⁻ recombines with a hole, the energy associated with this recombination is emitted as photons of light.



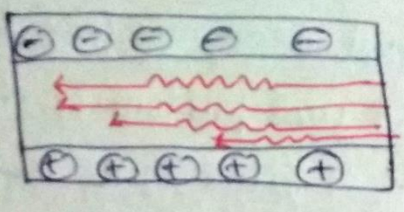
First emitted photon stimulates another excited e⁻ of light.



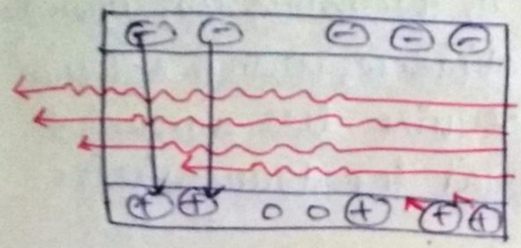
Two photons emitted having same wavelength being in same phase reflected by fully reflecting mirror.



New excited e^- & hole generated by a current that passes through semiconductor.

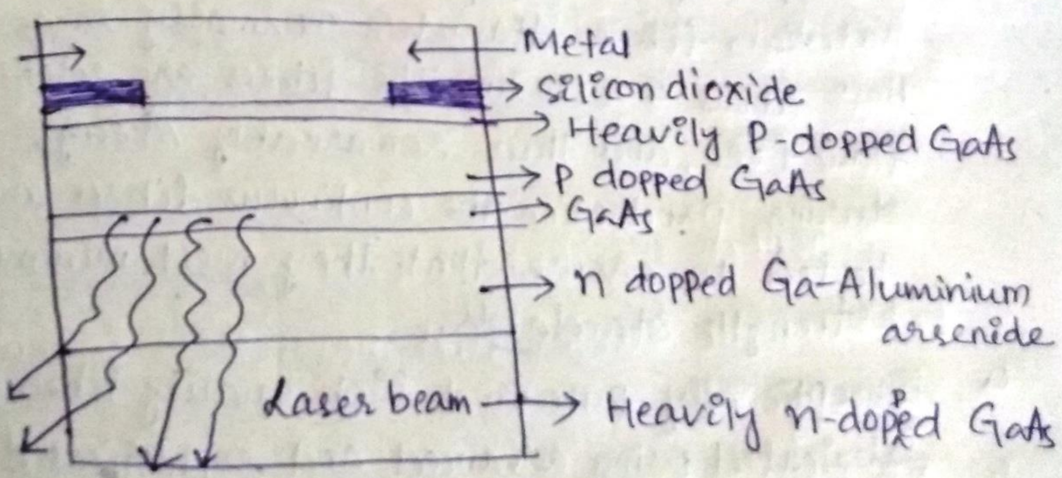


More stimulation occur.



Some portion of laser beams escapes through Partially reflecting mirror at one end of semicond--ucting material.

Semiconductor Laser :-



Here compositions of layers choosen so as to continue both the excited electrons & holes as well as laser beam to within the central GaAs layer.

Application: Surgical procedures, cutting, welding, machining etc.

Optical Fibres : Principle, structure and applicati

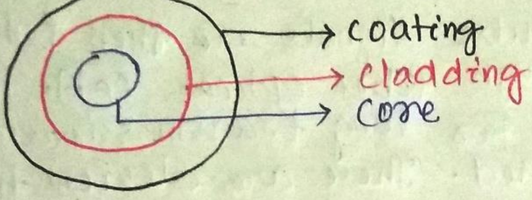
Development of optical fibres improves mode of communication. Signal transmission through metallic wire conductor is electronic whereas using optical transparent fibres, signal transmission is Photonic, it means it uses photons of electro-magnetic radiation. Use of fibre optic systems has improved speed of transmission, information density, transmission distance, with a reduction in error rate. It require less amount of fibre optical material for transmission.

Structure

↳ High purity silical glass is used as fibre material, fibre diameters normally range betn about 5 & 100 μm. The fibres are relatively flaw free, and thus remarkably strong; during production the continuous fibres are tested to ensure that they meet minimum strength standards.

↳ Exceptionally pure and high quality fibres are fabricated using advanced and sophisticated processing techniques. The presence of Cu, Fe & V is especially detrimental. Water & hydroxyl contaminants are extremely low. Bubbles within glass & surface have been virtually eliminated.

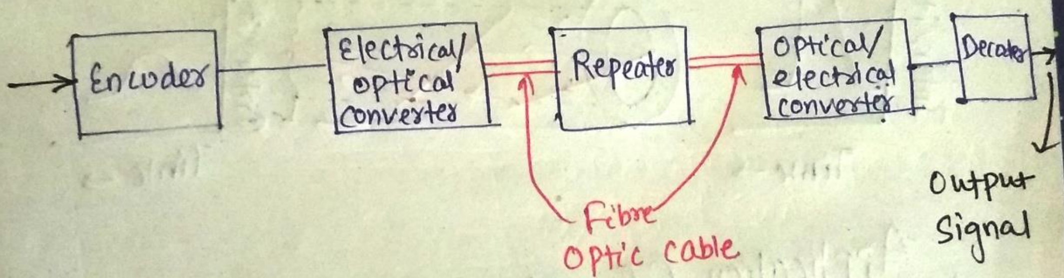
↳ Fibre components are core, cladding, and coating. Light rays travel in core, the outer coating protects core and cladding from damage that might result from abrasion and external pressures.



Working Principle

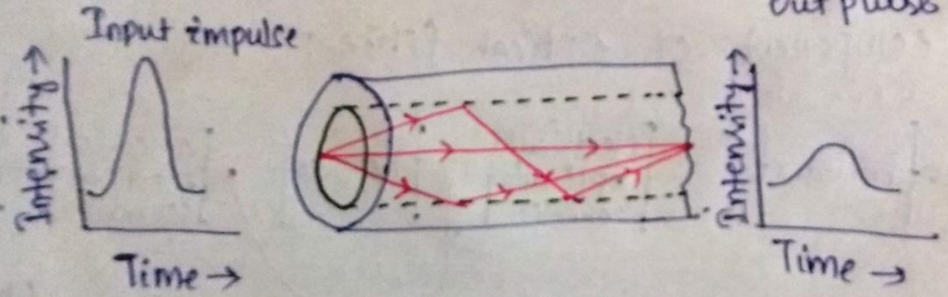
The main working principle behind optical fibre is <u>reflection</u>.

Components of optical fibre:



The information in electronic form must first be digitized in to bits, that is 1's and 0's; this is accomplished in the encoder. It is next necessary to convert this electrical signal into an optical one, which takes place in the electrical to optical converter. This converter is normally a semiconductor laser, which emits mono-chromatic and coherent light. The wavelength normally lies betn 0.78 & 1.6 μm, which is in the infrared region of electromagnetic spectrum; absorption losses are low within this range of wavelengths. The output from this laser converter is in the form of pulses of light; a binary 1 represented by high power pulse whereas '0' corresponds to low-power pulse.

↳ These photonic pulse signals are then fed into and carried through fibre-optical cable to the receiving end. For long transmissions repeaters may be required. These are devices that amplify and regenerate the signal. Finally at the receiving end the photonic signal is reconverted to an electronic one and is then decodded.



Application Of optical Fibres:-

Fibre optic cables find many uses in a wide variety of industries.

1. Medical

   Laser for surgeries, light guides, imaging tools.

2. Defense

   SONAR, wiring aircraft, submarines, field networking, hydrophones etc.

3. Data Storage
Used for data transmission

4. Tele communications
Transmitting and receiving purpose

5. Networking
Used to connect users, servers in a variety of network setting, help increase the speed & accuracy of data transmission.

6. Industrial
Wiring automobiles, sensor devices, temp, pressure and other measurements.

7. Broadcast
Internet, video on demand, cable connections etc.