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- **System** :- A body of matter completely cut off from its surrounding is known as system.

- **Phase** :- A phase is a physically distinct, chemically homogeneous and mechanically separable region of a system.

- **Phase diagram** :- It is a graphical ~~chart~~ chart which shows the relationship betn composition, temperature, time and structure of an alloy.

- **Pure-Metals** :- pure metals are often too soft and weak. used for many commercial application.

By alloying a pure metal in proper proportions with ~~other~~ metals and non-metals, a desirable mechanical and other properties can be developed in the material for example - steel is an alloy of iron and carbon and it is stronger than pure metal.

~~If~~ a pure metal is melted and the temperature is recorded and plotted at various intervals during cooling.

The pure metals may exist in more than one crystalline form, such crystalline forms is stable over more or less well defined limits of temperature and pressure. This is known as allotropy.

The pure iron exists in three allotropy forms. i.e:- alpha (α), gamma (γ) and delta (δ).
figure show the heating curve of pure iron,

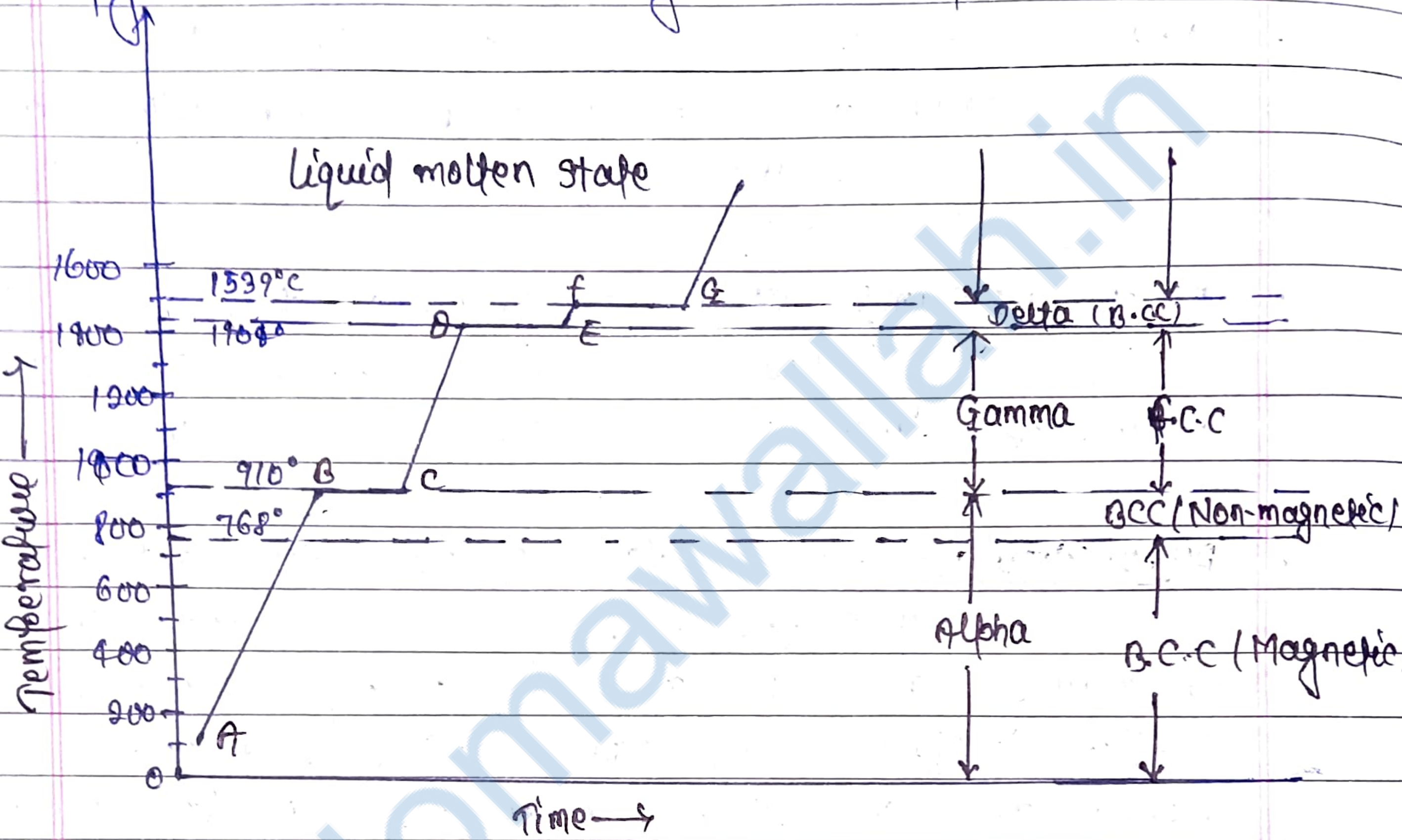


fig:- Heating curve of pure iron

pure iron has a body centred cubic (BCC) and is called α-iron. The α-iron is ferromagnetic at room-temperature, But on heating to 786°C, the ferromagnetism disappears. However, the crystal structure remains BCC.. Non-magnetic α-iron is stable up to 910°C. Above 910°C, it is transformed into face centred cubic (fcc) structure called γ-iron, upon heating upon 1404°C, the γ-iron is transformed back into the BCC structure called δ-iron. It is stable upto the melting point 1539°C of pure iron. The BCC structure of δ-iron has a longer cube edge than BCC structure of α-iron.

- **pure-metal :-** A pure metal is metal that consists of only one-type of metal element, without any significant amount of other elements or impurities.
  e.g :- Cu, Fe, Al, Ag, Pt etc

Alloys :- Alloys are mixture of two or more elements. In which one elements is metals. it is formed by melting two or more metal together.

e.g :- Brass = Cu + Zn
Bronze = Cu + Sn

properties of alloys :-

- It has more tensile strength
- It has more toughness
- It ~~has~~ is corrosion resistant
- It is harder than metal which are soft.
- It has high durability
- It has high Ductility.

purposes of Making alloys :-

- To improve Hardness.
- To lower the melting point
- To increase the corrosion resistance
- To increase Tensile strength.
- To improve casting property
- To Modify the colour
- To reduce Malleability and Ductility.

Solid Solutions :-

A solid solution is a homogeneous mixture of two or more ~~an~~ elements. where one element (the solvent) dissolves to another ~~nof~~ element (the ~~lattic~~ solute) in its crystal lattice.

- **Solute** :- A solute is the minor part of the solution.
- **Solvent** :- A solvent is the major portion of the solution.

- A solid solution is formed when the solute atoms are added to the solvent, w/ ~~without~~

e.g. :- Cu-Zn alloys (Brasses), Ni-Cu alloys (Moneal metal), Au-Ag alloys, Fe-C alloys (steels).

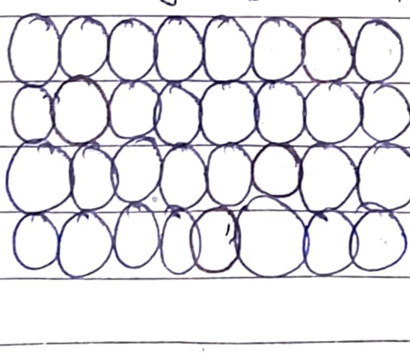
There are two types of solid solutions :-

i) Substitutional solid solution :

ii) Interstitial solid solution

1) **Substitutional solid solution** :- The solute atoms replace the solvent atoms in the crystal lattice.

e.g - Brass, Bronze, Sterling silver, steel etc

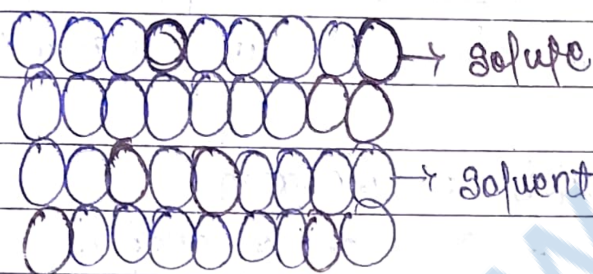


O = solvent

O = solute.

- if the solute atoms randomly occupy the solvent atom positions then the solid solⁿ is called <u>disordered substitutional solid solutions</u>.

- If the solute atoms are arranged in specific positions, such a solid solution is called <u>ordered solid solution</u>.



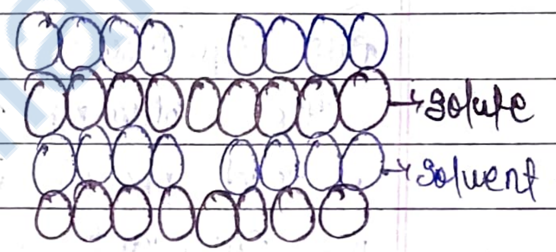
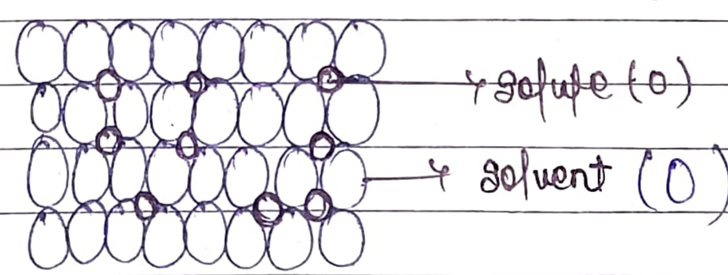


Fig. 1:- Disordered substitutional solid solution.

2) <u>Interstitial solid solution</u> :- The ~~Solute atoms replace the solvent atoms~~

The solute atoms occupy the interstitial spaces (void) betⁿ the solvent atoms in the crystal lattice.



Iron-carbon equilibrium diagram :-

The iron-iron carbide (fe-fe$_3$C) equilibrium diagram as shown in fig. In this diagram, the carbon composition is ~~plott~~ represented on horizontal axis and temperature is represented on vertical axis. The digram shows, the phase present at various temperature for very slowly cooled iron-carbon alloys with carbon content upto 6.7%.

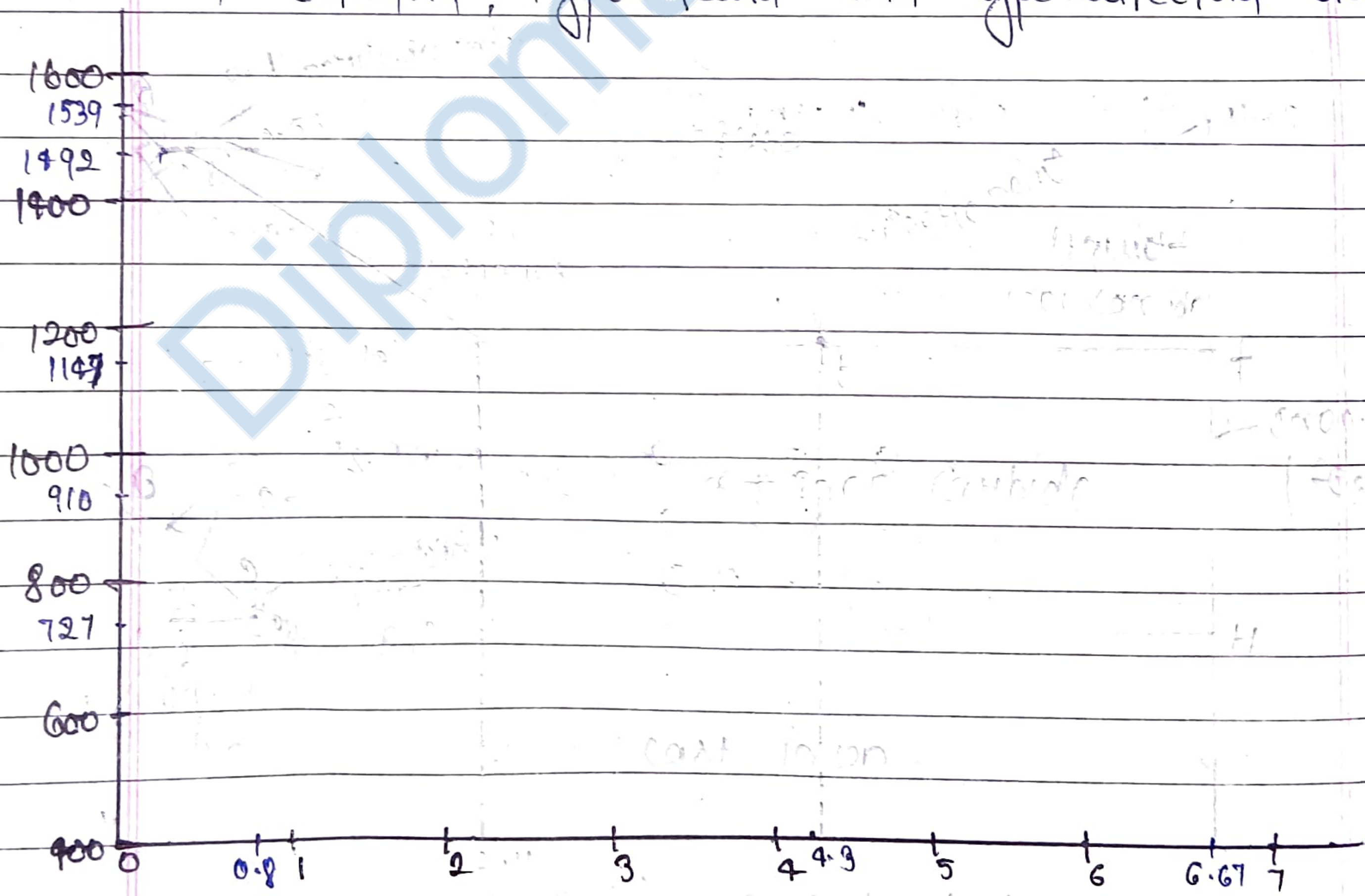
This equilibrium diagram gives us an information on the following points :-

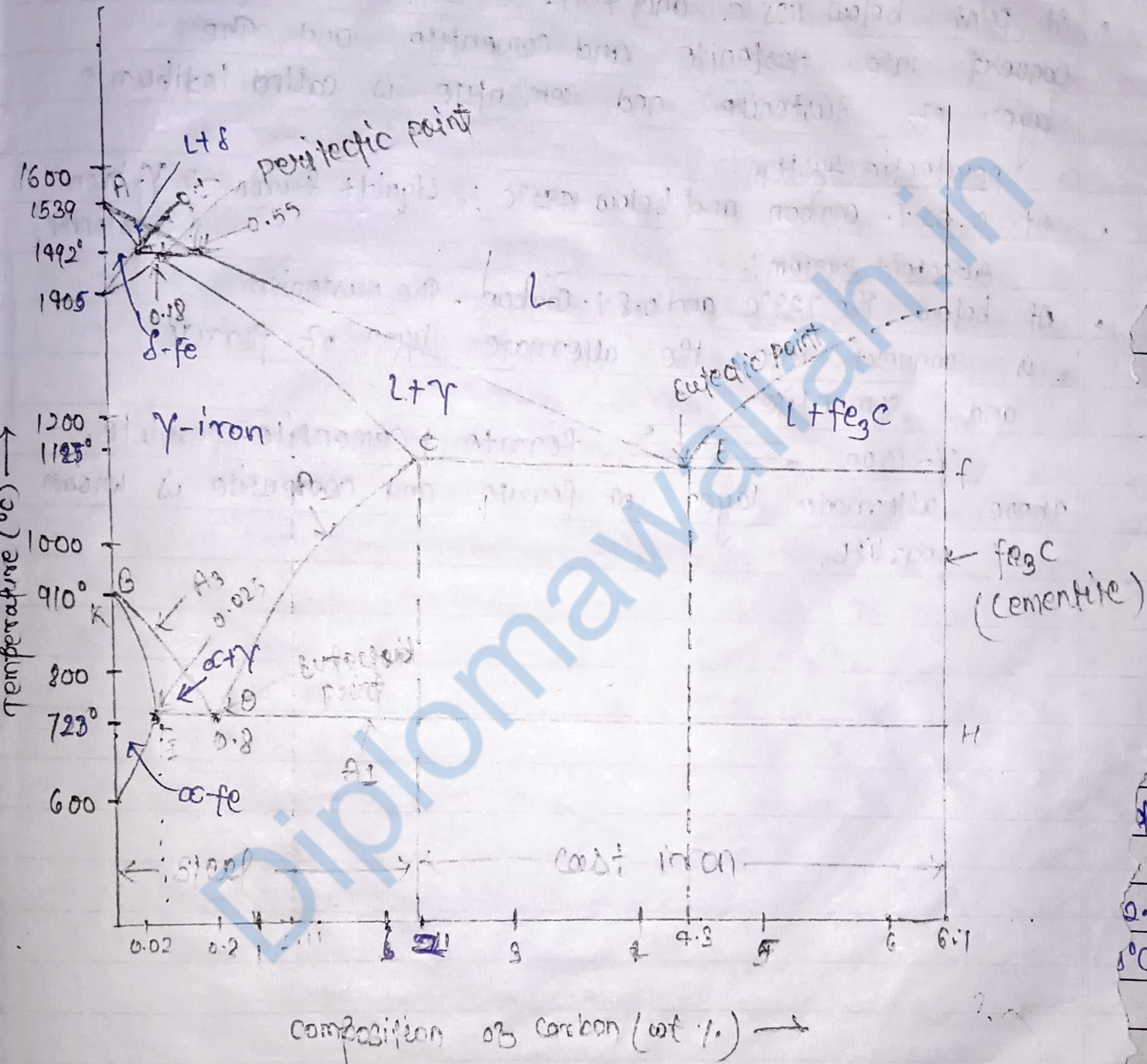
i) Solid phases in equilibrium diagram.

ii) Invariant reactions in the phase diagram

iii) critical temperature.

iv) Eutectoid, Hypoeutecoid and Hypereutectoid steels.





The cementite has negligible solubility limits and contains 6.7% carbon and 93.3% iron. cementite has an orthorhombic crystal structure with 12 iron atoms and 4-carbon atoms.

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Eutectic system:

- At point below 1125°C and 4.3% carbon. The liquid is convert into Austenite and cementite and the layer of Austenite and cementite is called ledeburite

peritectic system:-

- At 0.02% carbon and below 1492°C :- Liquid + δ-iron → γ-iron (Austenite)

eutectoid system:-

- At below the 723°C and 0.8% carbon. The Austenite is convert into the alternate layer of ferrite and cementite.

γ-iron ⇌ ferrite + cementite = pearlite.

These alternate layer of ferrite and cementite is known as pearlite.

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The low-carbon region is found at 1400°C in the phase diagram. The region lying in the 700-900°C temperature range and 0-1% carbon-range is the most important region in the phase diagram. In this region an engineer can develop those microstructures which are required for desired properties within the steel.

The iron-iron carbide phase diagram shown in fig. contain the four-solid phase i.e α-ferrite, austenite (γ), cementite (Fe_3C) and δ-ferrite.

i) α-ferrite:- The solid solⁿ of carbon in α-iron is called α-ferrite. This phase has BCC structure. The maximum solid solubility of the carbon in α-ferrite is 0.02% at 723°C. The solubility of carbon in α-ferrite decreases with decrease in temperature, until it is about 0.008% at 0°C as shown by the line GM in the phase diagram.

ii) Austenite:- The solid-solⁿ of carbon in γ-iron is called austenite. It has a FCC structure. The solubility of carbon in austenite reaches a maximum of 2.11% at 1148°C and then decreases to 0.8% at 723°C as shown by the line CD in the phase diagram.

iii) Cementite:- The intermetallic iron-carbon compound is called iron carbide or cementite.

The cementite has negligible solubility limits and contains 6.7% carbon and 93.3% iron. Cementite has an orthorhombic crystal structure with 12 iron atoms and 4-carbon atoms.

iv) **δ-ferrite:-** The solid-soln of carbon in δ-iron is called δ-ferrite. It has a BCC crystal structure. The maximum solid solubility of carbon in δ-ferrite is 0.09% ~~and~~ at 1495°C.

Q. What is critical temperature? Explain its significance.

Ans. Critical temperature and its significance:-

The temperature at which the structural changes takes places is called critical temperature (or point). The critical temperature vary with the composition of carbon in iron.

- A_3 - upper critical temperature (point) for steels with carbon content up to 0.8% and are given by a line GE
- A - upper critical temperature for steels with carbon content from 0.8% to 2.8% and given by a line CO.
- A_1 - lower critical temperature for steel corresponds to line GDH at 723°C
- A_2 - Magnetic transformation temperature is the temperature below which α-ferrite is ferromagnetic.

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phase composition :-

Iron carbon alloys containing carbon from 0 to 1.4%. are called steels. These are called as plane carbon steel when they do not contain any alloying element.

Eutectoid steel :- A plain carbon steel containing 0.8% carbon is known as eutectoid steel.

Hypoeutectoid steel :- A plain carbon steel contains less than 0.8% carbon is known as hypoeutectoid steel.

Hypereutectoid steel :- A plain carbon steel containing more than 0.8% carbon is known as hypereutectoid steel.

The iron-carbon alloys containing carbon from above 2% to 4.8% is called cast-iron.

- The cast-iron containing 4.3% carbon is called ~~electoid~~ Eutectoid cast iron.
- The cast-iron containing ~~+~~ less than 4.3% carbon is called hypoeutectoid cast iron.
- The cast-iron containing more than 4.3% carbon is called hypereutectoid cast-iron.

Q. What are the invariant reactions in the iron-carbon equilibrium phase diagram.

A horizontal line always indicates an invariant reaction in phase diagram:-

Peritectic reaction at 1492°C and ~~0.18~~ 0.02 % C

δ-ferrite + liquid ⟷ γ-iron (Austenite)

- A reaction where a solid phase and liquid phase will together form a second solid phase at a particular temperature and composition.

  i.e:- liquid + solid 1 $\underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}}$ New solid (S_2)

Eutectic reaction at ~~1148~~ 1125°C and 4.3 % C

Liquid ⟷ γ-iron + Fe_3C
(Austenite) (Cementite)

- A eutectic reaction is a three-phase reaction, by which on cooling a liquid transforms into two solid phases at the same time.

Eutectoid reaction at 723°C and 0.8 % C

γ-iron (Austenite) ⟷ α-ferrite + Fe_3C
(pearlite)

- The eutectoid reaction involves a single solid phase decomposing into two different solid phases.

  i.e:- solid 1 ⇌ solid 2 + solid 3

Heat treatment :-

Heat treatment is the process of heating and ~~coll~~ cooling metals or alloys to obtain their physical and mechanical properties without changing the shape of the object.

OR

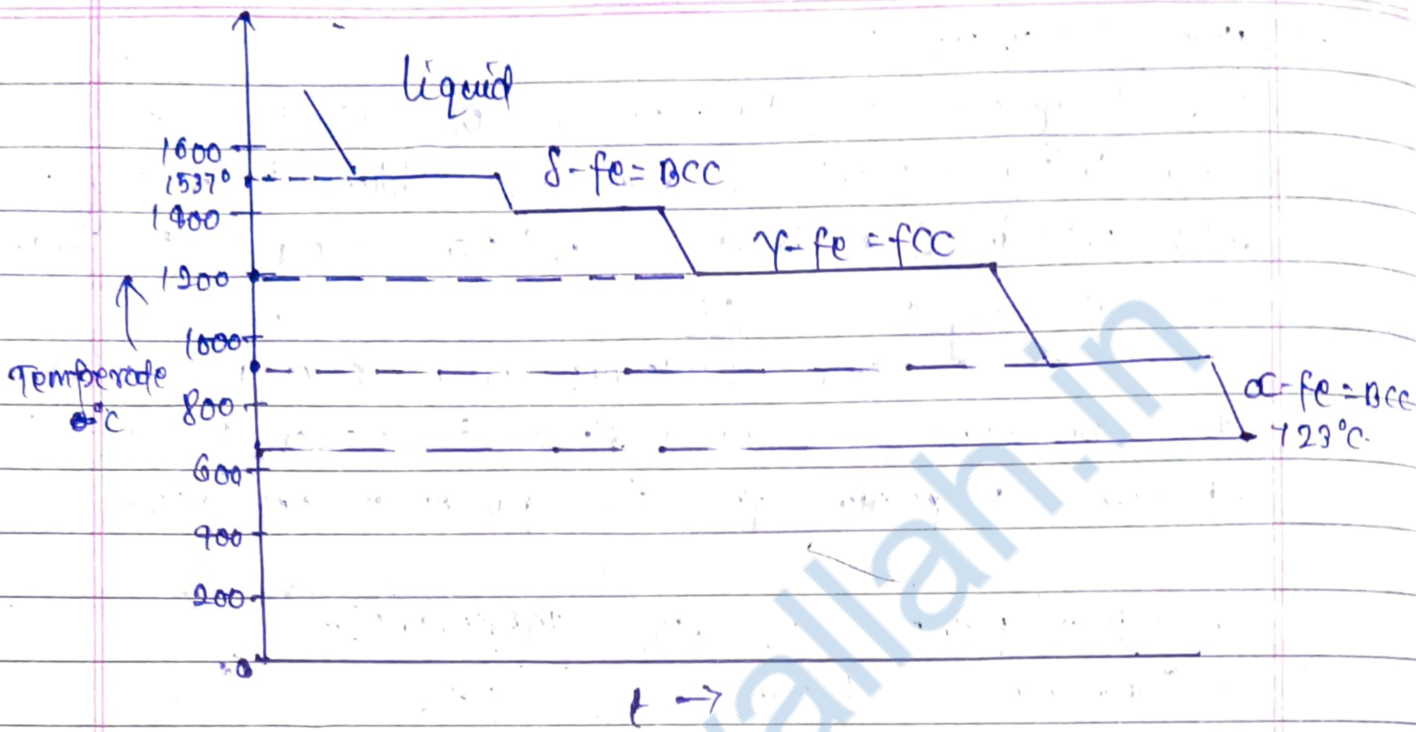
Heat treatment is a process in which different operation are involved to obtain the suitable/desirable properties for the particular application.

objective/ purpose of heat treatment :-

i) To Increase the hardness of metal.
ii) To relieve the internal stresses.
iii) To soften the metal
iv) To improve the machinability
v) To refine the grain structure
vi) To improve the electrical and magnetic properties.
vii) To improve mechanical properties like tensile strength, ductility and shock resistance etc.
viii) To increase ~~the resistance to~~ wear, tear, heat and corrosion resistance.

Mechanism of Heat treatment :-

i) Heating the metal to a certain/specified temperature.
ii) Holding the metal at that increased temperature for a specified period.
iii) Then cooling the metal slowly in air or by quenching [medium].
iv) A metal or alloys is heated depend upon it grade, grain as well as type and shape.



Types of heat treatment:-

1) Annealing
2. Normalising
3. Hardening
4) Tempering
5. Carburing
6. Cyaniding
7) Nitriding

1) **Annealing**:- Annealing is the heat treatment process in which a material is heated to a specific temperature or above the critical temperature and holding at that temperature for a certain suitable time period. and then allow ~~it to cool slowly~~ cooling it slowly in the furnance.

purpose of Annealing :-

i) To soften the metal
ii) To improve the machinability
iii) To refine grain size due to phase recrystallisation
iv) To increase ductility of metal.
v) To modify electrical and magnetic properties.
vi) To relieve internal stresses.
vii) To remove gases.
viii) To produce a definite microstructure
ix) To reduce brittleness.

application of Annealing :-

i) used for machined parts to improve it properties
ii) used for steel production (sheets, plates, bars).
iii) used for Aerospace component
iv) used for construction material (beams, pipes)
v) used for electrical component (transformers, motor).
vi) used for medical equipment

The annealing temperature range varies depending on the materials.

i) for steel :- 649°C - 788°C
ii) cast iron :- 649°C - 704°C
iii) Aluminium alloys :- 413°C - 496°C
iv) Copper alloys :- 482°C - 566°C
v) stainless steel :- 1038°C - 1121°C

2) <u>Normalising</u> :- Normalising is a heat treatment process in which a material is heated at a specific temperature and holding that ~~tempture~~ temperature for specific period of time and then cooling it in air.

<u>purpose/objective of ~~An~~ Normalising</u> :-

i) To increase the strength of medium carbon steel.
ii) To improve machinability of low carbon steel.
iii) To reduce internal stresses
iv) To improve mechanical properties like - strength, toughness, ductility etc.
v) To improve electrical properties
vi) To remove grain structure obtained during forging, rolling and stamping.

<u>Application</u> :-

i) used in steel production (plates, sheets, bars)
ii) used in forging and casting industries to refine grain structure and to relieve stresses.
iii) Automotive and aerospace components.
iv) Construction materials
v) Machine parts (gears, shafts).
vi) used in automobile industry for stamping of ferritic stainless steel.

Temperature range -

i) steel - 843°C - 927°C
ii) cast iron :- (843°C - 871°C)
iii) Al - alloys :- (482°C - 538°C)

3. <u>Tempering</u> :- Tempering is a heat treatment process in which a material is heated to a specific temperature below its critical temperature and holding that temperature for a specific period of time and then cooled.

<u>Purposes</u> :-

i) To ~~revom~~ remove the internal stresses due to rapid cooling of steel.
ii) To reduce brittleness of hardned steel.
iii) To increase the ductility.
iv) To increase the toughness of steel.
v) To change the volume
vi) To reduce the hardness.
vii) To ~~a~~ stabilise / balance the structure.

Application :-

i) used for tempering springs, screw drivers, cold chisels etc
ii) used for tempering drills and milling cutters.
iii) used for tempering punches, reamers, twist drills etc.
iv) used for press tools, axes, etc.
v) used for cutting tools (knives, blades)
vi) used for medical equipment
vii) sports equipment (golf clubs, tennis rackets)
viii) used in Aerospace components.
ix) used in automotive parts (axels, gears, spring)

Temperature range :-

i) steel :- 149°C - 316°C
ii) cast iron :- 204°C - 371°C
iii) Al-alloys :- (149°C - 260°C)
iv) stainless steel :- 316°C - 482°C

Types of Tempering :-

i) low tempering :- performed at low temperature (300°f-500°f) to reduce brittleness and relieve internal stresses.

ii) Medium tempering :- performed at medium temperatures (500°f - 700°f) to achieve a balance of hardness and toughness.

iii) High tempering :- performed at high temperatures (700°f-900°f) to increase toughness and reduce hardness

iv) Double tempering :- A two-stage process involving two separate tempering cycles to achieve specific properties.

v) Isothermal tempering :- performed at a constant temperature to achieve specific properties.

4. Hardening :- Hardening is a heat treatment process in which a material heated to a specific temperature and holding that temperature at specific period of time and then rapidly cooled in water.

purpose :-

i) To increase the hardness of the metal.
ii) To increase the wear resistance capacity of the metal.
iii) To make it suitable for cutting tool.
iv) To increase the strength.
v) To enhance fatigue life

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Application:-

i) used in steel production (tools, dies, machinery)
ii) Automotive parts (gears, axles, spring)
iii) used for Aerospace components.
iv) used for construction materials
v) used for cutting tool (knives, blades)
vi) used for medical equipment.
vii) used for sports equipment

Temperature range:-

i) Steel:- 816°C - 927°C
ii) Cast iron:- 843°C - 899°C
iii) Aluminium-Alloy:- (482°C - 538°C)
iv) stainless steel:- 982°C - 1093°C

Q. what is case hardening? state its purposes?

Ans) case hardening is a heat treatment process in which ~~heating~~ the surface of material (steel) is heated to a high temperature and then rapidly cooling it. to create a hard, wear resistance surface layer, known as the "case". This process is also known as surface hardening.

purpose:-

i) To obtain hard and wear resistance surface in machine parts.
ii) To increase fatigue strength.
iii) To enhanced corrosion resistance
iv) To obtain/retains tough core.
v) To improved durability
vi) To obtain high mechanical properties in the core.

Application of case-hardening :-
i) Gear ii) Ball Bearing iii) Railway wheels (iv) cutting tools
(v) Axles
(vi) Automotive components (e.g. engine parts).
(vii) Aerospace components.

explain the types of case hardening :-
1) Carburising
2) Nitriding
3) Cyaniding.

1) Carburising :- Carburising is a type of case hardening or a heat treatment process that involves adding carbon to the surface of a material (steel) to create a hard, wear-resistance surface layer.

steps involved in carburising :-

i) Heating :- The material is heated to a high temperature in a furnace.

ii) Carbon addition :- Then carbon is added to the material through a gas, liquid or solid medium.

iii) Diffusion :- Then the carbon diffuses ~~with~~ into the surface layer of the material, creating a carbon-rich zone

iv) Quenching :- The material is rapidly cooled using oil, water or air.

v) Tempering :- The material is reheated to a lower temperature to reduce brittleness and achieve the desired hardness.

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2. **Nitriding** :- Nitriding is a type of case-hardening or a heat treatment process that involves nitrogen is diffuses into the surface of a material (steel), to create a hard, wear-resistant surface layer. This process is used to improved the material's properties.

Steps involved in Nitriding :-

i) **Heating** :- The material is heated to a temperature range of 500°C to 600°C.

ii) **Nitrogen addition** :- Nitrogen gas is added to the surface of materials.

iii) **Diffusion** :- The nitrogen diffuses into the material, creating a nitrided layer.

iv) **cooling** :- The material is slowly cooled to prevent distortion or cracking.

3. **Cyaniding** :- Cyanding is a type of case hardening process or a heat treatment process that involves heating a material (steel) and carbon and nitrogen from the cyanide salts diffuse into the surface layer of a material.

i) **Heating** :- The material is heated to a temperature range of 800°C to 900°C.

ii) **Cyanide salt bath** :- The material is immersed in a bath of molten cyanide salts i.e. $NaCN$ or KCN

iii) **Diffusion** :- carbon and nitrogen from the cyanide salts diffuse into the surface layer of the material.

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