UNIT- I

MATERIAL SCIENCE:

→ It based on the physics and chemistry of the internal structure of materials.

→ Investigates Relationships existing between the Structure of materials and their properties.

→ Deals with all materials, e.g. metals, ceramics, glasses, Organic plastics and polymers, wood and stone.

METALLURGY:

→ Metallurgy is the Science and technology of metals.

→ Metallurgy embraces the Practice and Science of

(i) Extracting metals from their ores.

(ii) Refining of crude metal.

(iii) Production of alloys and the Study of their constitution, Structure and properties

(iv) The relationship of physical and mechanical properties thermal and mechanical treatment of metals and alloys.

CLASIFICATION OF METALLURGY :-

★ Extractive OR CHEMICAL METALLURGY

★ MECHANICAL METALLURGY

★ PHYSICAL METALLURGY

EXTRACTIVE METALLURGY :-

→ It deals with the liberation of metals by various chemical processes from the ores in which they are found. The extractive metallurgy is also charged with Refining the metals to a purity that can be used in industry.

→ It includes mining, concentration, extraction and refining of metals and alloys.

→ This is subdivided in two categories

→ Ferrous

concerned with iron and steel and the alloys of iron and steel.

→ NON-FERROUS

encompasses all metals and alloys with the exception of Iron and steel and their alloys.

MECHANICAL METALLURGY:-

Metals owe their importance to their unique mechanical properties, the combination of high strength with the the ability to change shape plastically (ductility and malleability).

→ It is an alloy in which the atoms of solute are distributed in the solvent and has the same structure as that of the solvent. Solid solutions have different compositions with similar structures and are like liquid solutions such as sugar in water.

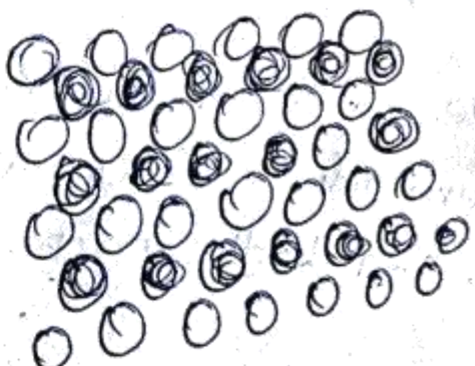
Solid solutions are of two types:

(i) Substitutional (ii) Interstitial.

→ Substitutional solid solution means the atoms of B element i.e., solute are substituted at atomic sites of A element i.e., solvent. Depending on the distribution of B atoms in A.

these classified into two types:

(A) Regular or ordered (B) Random or Disordered



(a) Regular
(Ac-Cu solid solution below 400°c)

(b) Random

In Interstitial solid solutions, the atoms of B occupy the interstitial sites of A. This type of solid solution formation is favoured when the atomic size of B is very much small as compared to the atomic size of A.

Intermediate Alloy phases :-

→ When an alloying element (solute) is added to a given metal (solvent) in such an amount that the limit of solid solubility is exceeded, a second phase appears with the solid solution. It may be solid or intermediate phase.

→ This may differ in composition as well as crystal structure from parent metal so properties are also differ.

→ Some intermediate phases have a fixed composition and they are called as intermediate compounds. Generally these have hard, and brittle properties and high melting points.

→ The intermediate phases in which the Ratio of number of free electrons to the number of atoms is constant are called electron compounds and they are exhibit similar characteristics.

SOLID SOLUTION:-

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(a) Regular

(Ac-Cu solid solution below 400°c)

(b) Random

→ This plasticity enables them to be shaped, e.g. into car Bodies, tin Cans, by processes of Mechanical working such as pressing, drawing, rolling and forging.

PHYSICAL METALLURGY:-

→ Few things in nature Seems more inanimate than a piece of metal. The casual observer sees only his own reflection in its bright, still Surface and nothing of its world within.

→ even metal is completely Solid changes of temperature can cause the atoms to rearrange them.

it can happen in few Seconds.

→ In a quenching ~~Stebb~~ Steel

like solid solutions, intermediate phases also exhibit order-disorder transformation e.g. β brass in Cu-Zn alloy system is disordered above 453 to 470°C depending on the composition of the alloy and ordered at lower temperature.

HUME-ROTHERY'S RULES OF SOLID SOLUBILITY

In formation of solid solution, the solubility limit of solute in the solvent is governed by certain factors. These are known as Hume-Rothery's Rules of solid solubility. They are as below:

(i) ATOMIC SIZE FACTOR:-

If the atomic sizes of solute and solvent differ by less than 15%, It is to have a favourable size factor for solid solution formation. If the atomic size difference exceeds 15%, solid solubility is limited.

(ii) Chemical AFFINITY FACTOR:-

The greater the chemical affinity of two metals, the more restricted is their solid solubility and greater is the tendency of formation of a compound. Generally, wider the seperation of elements in the periodic table, greater is their chemical affinity.

(iii) RELATIVE VALENCY FACTOR:-

A metal of higher valency can dissolve only a small amount of a lower valency metal, while the lower valency metal may have good solubility for the higher valency metal.

(iv) CRYSTAL STRUCTURE FACTOR:

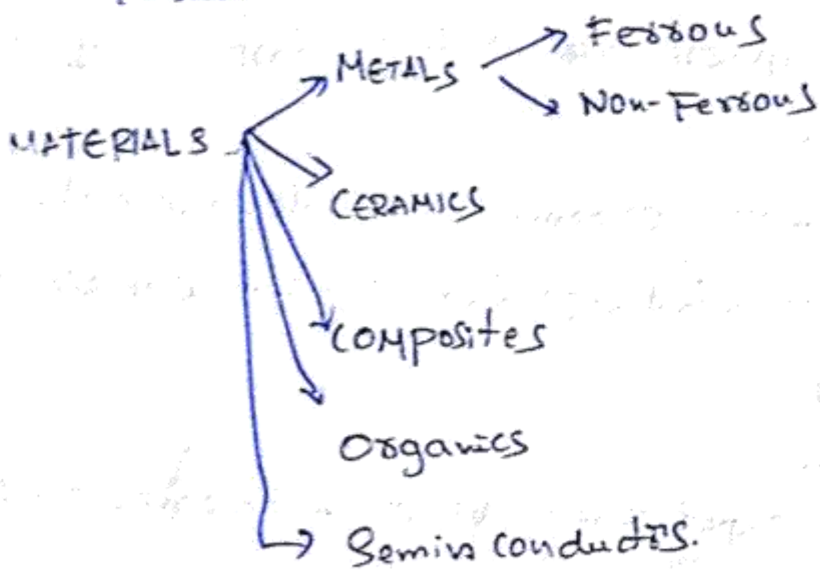
Metals having same crystal structure will have greater solubility. Difference in crystal structure limits the solid solubility.

For continuous solid solubility, atomic size difference should preferably be less than 8% with other factors favourable.

ENGINEERING MATERIALS :-

A material is that out of which anything is or may be made. A material relates itself to matter.

Materials comprise a wide range of metals and non-metals which must be operated upon to form the finished product.



(a) METALS :-

Metals are composed of elements which readily give up electrons to provide a metallic Bond and electrically conductivity.

Ex: Iron, Aluminium, copper, Zinc, Magnesium, etc.

(b) CERAMIC MATERIALS :-

→ Ceramics usually consist of Oxides, nitrides, Carbides, Silicates or Borides of various metals.

→ Ceramics are any inorganic, non-metallic solids processed or used at high temperatures.

→ Ceramics are Rock & clay mineral materials.

→ Examples:-

(a) Sand, Brick, concrete, Glass; cement, insulators, Silicon carbide, Tungsten CarBide, Boron Carbide, Refractories, ABrasives, plaster

c) ORGANIC MATERIALS:-

→ They are polymeric materials composed of carbon compounds polymers are Solids composed of long molecular chains.

→ There are countless organic materials, natural, Synthetic & manufactured and based chemical on CarBon.

Examples:-

Rubber, plastics, Paper, Fuels, wood, Lubricants, Textiles, Paints and finishes, Adhesives, Explosives.

Applications:-

(i) As electric insulation.

(ii) For improving appearance.

(iii) As Fuels.

(iv) As vitamins and medicines

(v) As refrigerants

(vi) As Lubricants etc.

Polymers:-

polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically Based on Carbon, hydrogen and other non Metallic elements.

MECHANICAL PROPERTIES :-

Mechanical properties determine the behaviour of Engineering materials under applied forces and loads. Various Mechanical properties are:

(1) ELASTICITY :-

Tendency of a deformed solid to seek its original dimensions upon unloading ascribed to a property called elasticity.

(2) PLASTICITY :-

plasticity is that property of a material by virtue of which it may be permanently dormed when it has been subjected to an externally applied force great enough to exceed the elastic limit.

(3) TOUGHNESS :-

→ Toughness is the ability of the material to absorb energy during plastic deformation up to fracture.

→ Toughness refers to the ability of a material to withstand bending or the application of shear stresses without fractures.

(d) COMPOSITES :-

It consists of more than one material type. Fiber-glass is a familiar examples.

Glass + polymer = Fiberglass.
(strength) (flexibility)

(e) SEMICONDUCTORS :-

Semiconductors have electrical properties that are intermediate between the electrical conductors and insulators.

PROPERTIES OF ENGINEERING MATERIALS :

→ Mechanical properties
→ Thermal properties
→ Electrical properties
→ Magnetic properties
→ Chemical properties
→ optical properties
→ physical properties
→ Technological properties.

(4) RESILIENCE:-

→ Resilience is closely related to toughness.

→ Resilience is the capacity of a material to absorb energy when it is elastically deformed and then upon unloading, to have this energy recovered.

(5) TENSILE STRENGTH:-

Ratio of the maximum load to ~~orgara~~ original cross-sectional area is called Tensile strength & ultimate tensile strength.

(6) YIELD STRENGTH:-

When metals are subjected to a tensile force, they stretch elongate, as the stress increases. The point where the stretch suddenly increases, is know as yield strength.

(7) IMPACT STRENGTH:-

capacity material to resist & absorb shock energy.

(8) DUCTILITY:-

Capacity of a material to undergo deformation under tension without rupture.

(9) MALLEABILITY:

→ Malleability is the capacity of a material to withstand deformation under compression without rupture as for example in forging and rolling operations.

→ The ability of a metal to be formed by hammering or rolling is called malleability.

(10) BRITTLENESS:-

It is defined as a tendency to fracture without appreciable deformation and is therefore the opposite of ductility or malleability.

(11) HARDNESS:-

It is the resistance of a material to plastic deformation usually by indentation.

(12) FATIGUE:-

When subjected to fluctuating or repeated load, materials tend to develop a characteristic behaviour, which is different from that under steady loads.

(13) CREEP:-

Creep is the time-dependant permanent deformation that occurs under stress.

CRYSTALLOGRAPHY:-

→ Crystallography is the Study of the Crystal formation of Solids
→ is a branch of Science in which the internal Structure of Crystals, their properties, external & internal Symmetries of Crystals are Studied.
→ when it is applied to metals it is called "Metallography"

→ TERMS ASSOCIATED WITH CRYSTALLOGRAPHY

(1) CRYSTAL
(2) STRUCTURE
(3) SPACE LATTICE
(4) UNIT CELL
(5) CRYSTALLOGRAPHIC PLANES
(6) LATTICE PARAMETER
(7) MILLER INDICES
(8) ATOMIC PACKING FACTOR
(9) COORDINATE NUMBER.

(1) A CRYSTAL is a solid whose constituent atoms & molecules are arranged in a Systematic geometric patterns
(2) The STRUCTURE implies the arrangement and disposition of the atoms within a Crystal.
(3) The atoms arrange themselves in distinct pattern in Space called Space Lattice.
(4) The UNIT CELL is the Smallest group of atoms possessing the Symmetry of the crystal.
(5) The Layers of atoms & the planes along which atoms are arranged are known as ATOMIC (or) CRYSTALLOGRAPHIC PLANES.

(6) Characteristic intercepts and interfacial angles of a crystal constitute the LATTICE PARAMETERS of a cell.

(7) MILLER INDICES is a System of notation for designating Crystal-lographic planes and directions of Crystals.

(8) ATOMIC PACKING FACTOR: is the ratio of the volume of the atoms per unit cell to the total volume occupied by the unit cell.

(9) coordinate number is the number of nearest atoms directly surrounding a given atoms in a crystal i.e., nearest neighbours to an atoms in a crystal.

TYPES OF SOLIDS:-

Solids in which atoms are closely packed.

Solids may be classified in to three

(a) Crystalline - if atoms or molecules arranged in Regular fashion.

(b) Amorphous - IRRegular fashion.

(c) A combination of two

BONDS IN SOLIDS:-

- All solids are composed of a very large no of atoms that are bonded together in some manner.
- The cohesion between the atoms is dependent upon the character of the individual elements.

- BONDING ENERGY:-

- Defined as the energy required to return the atoms to an infinite seperation.
- It is also be expressed as the energy of formation of 1 mole of a substance from its atoms or ions when brought together from an infinite distance to the equlibrium position.

TYPES OF BONDS:-

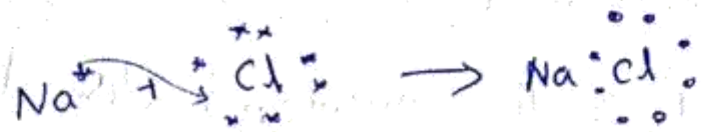
(a) Primary Bonds →
- → Ionic
- → covalent
- → Metallic

(b) Secondary Bonds – Van der Waals Bond. (Molecular Bond)

IONIC BOND:

- Ionic Bond is also known as electrovalent (or) hetero polar Bond.

→ It is an Simple example of Interatomic Bonding.

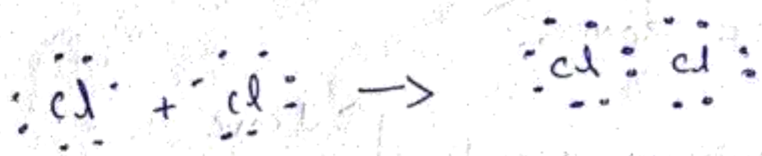


→ It Exists between a metallic atom (sodium) and a non-metallic atom. (chlorine)

COVALENT BOND:-

→ covalent Bond is also known as homo polar Bond.

→ when electrons shared Between atoms it gives rise to a covalent Bond.



METALLIC BOND:-

→ It appled to metals and alloys.

→ It is an Special form of covalent Bonding.

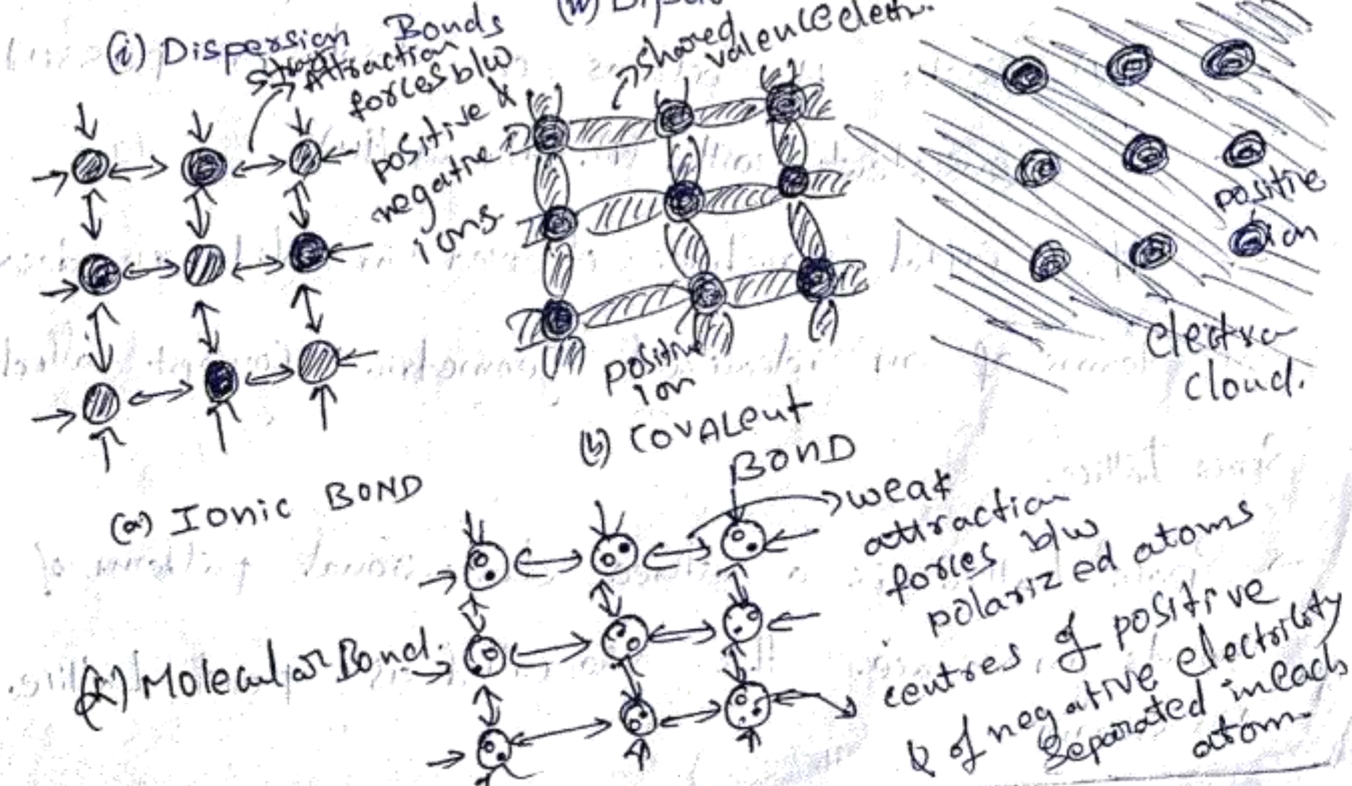
→ In Covalent bonding particular atoms in the Structure are linked together by particular pairs of the valency electrons shared between them.

→ whereas, in metallic bonding, the valency electrons are not bound to any particular pairs of atoms but

move freely throughout the metal and form a negative electron cloud. which shared by positive ions.
→ atoms having small number of valence electrons which are loosely held, so that they easily be released to the common pool (cloud).

(d) THE VAN DER WAAL BOND (or Intermolecular Bond):-
→ Inter molecular or Van der Waal forces are weak forces that account for mutual interaction between molecules or inert atoms.
→ week electrostatic attraction is due to unsymmetrical electrical charges in electrically neutral atoms or molecules.
→ Inter molecular forces account for the properties of liquids and many molecular solids ranging from small molecular weight up to polymers.

→ THREE TYPES (i) Dispersion Bonds (ii) Dipole Bonds (iii) Hydrogen Bonds.



CRYSTAL STRUCTURES :-

→ They are regular three Dimensional patterns of atoms in Space.

→ This regularity of atomic arrangement in solids come due to geometrical conditions which are imposed by directional bonding and/or close packing of atoms.

→ The most stable arrangement of atoms in a crystal will be that arrangement which minimizes the energy per unit volume i.e., in other words, the one that:

(i) Preserves electrical neutrality

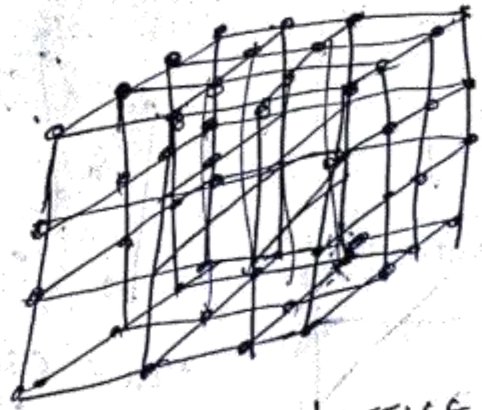
(ii) Satisfies the directionality and discreteness of all covalent Bonds.

(iii) Minimizes Strong ion-ion repulsion.

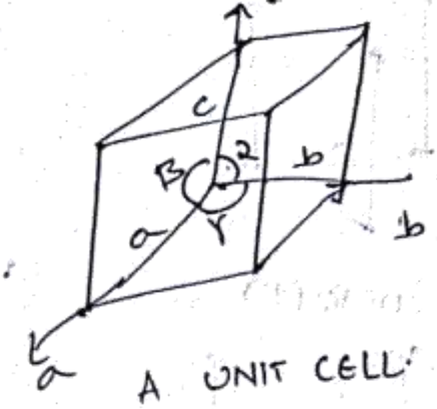
(iv) Packs the atoms as closely as possible consistent with (i), (ii) and (iii)

→ The Crystal structures observed in Solids are described in terms of an idealized geometric concept called a Space Lattice.

→ Space Lattice is a three dimensional pattern of points in Space. this also called as point Lattice. As shown.



A point LATTICE



A UNIT CELL

a, b, c, α, β, γ → Lattice parameters.

Lattice points can be arranged in only 14 different arrangements (arrays). Called "Bravais LATTICE"

CRYSTAL SYSTEMS AND BRAVAIS LATTICE :—

SYSTEM	AXIAL LENGTHS AND ANGLES	BRAVAIS LATTICE	LATTICE SYMBOL
CUBIC	Three equal axes at right angles, $a=b=c$, $\alpha=\beta=\gamma=90°$	Simple Body-centred Face-centred	P I F
TETRAGONAL	Three axes at right angles, two equal, $a=b\neq c$, $\alpha=\beta=\gamma=90°$	Simple Body-centred	P I
Orthorhombic	Three unequal axes at right angles, $a\neq b\neq c$, $\alpha=\beta=\gamma=90°$	Simple Body-centred Base-centred (end) Face-centred	P I C F
Rhombohedral	Three equal axes, Equally inclined, $a=b=c$, $\alpha=\beta=\gamma\neq 90°$	Simple	R
Hexagonal	Two equal coplanar axes at 120° third axis at right angles, $a=b\neq c$, $\alpha=\beta=90°$, $\gamma=120°$	Simple	P
MONOclinic	Three unequal axes, one pair not at right angles, $a\neq b\neq c$, $\alpha=\gamma=90°\neq\beta$	Simple Base-centred (end)	P C
TRICLINIC	Three unequal axes, unequally inclined and none at right angles $a\neq b\neq c$, $\alpha\neq\beta\neq\gamma\neq 90°$	Simple	P

UNIT - II

PHASE DIAGRAMS (OR) EQUILIBRIUM OF DIAGRAMS

* Phase diagrams also known as equilibrium diagrams are very important tool in the study of alloys.
* A phase diagram has temperature as its ordinate and alloy composition as abscissa
* The objective of phase diagram shows at a glance the phases which exit in equilibrium for any composition of, temperature and alloy composition.
* Equilibrium refers to the state of behave which exists (or) which tends to be attained, between the phases in the structure of an alloy after a physical & chemical changes has taken place.
* It shows relationship between the composition, temperature and structure of an alloy in series.

→ Phase separation
→ Solidification of metals and alloys
→ Purification of Material
→ The structural changes produce by heat

treatment.

Classification of phase diagrams

1) Unary
2) Primary
3) Ternary.

Unary :- This is also called one component phase diagrams plotted as pressure on the vertical and temperature on the horizontal axis.

Primary : (Two - component) Phase diagrams which finds extensive uses and

Ternary :- (For three components)

* Systems, Phases and Structural Constituents

* A system is a substance (or group of substances) so isolated from its surroundings that is unaffected in over all composition temperature, pressure or total volume only to the extent allowed by investigator.

* Phase can be defined as any part or portion of a chemical system which possess distinctive physical characteristics

Q to R remains constant, until whole mass has entirely solidified (at point R)

⇒ Between Q and R, the mass is partly liquid and partly solid, at a point is solid

a: pure metal

b: Binary metal

c: Binary Eutectic metal

PHASE DIAGRAM

* An equilibrium digram shows the units of composition and temperature within which the various constituents & phases of an alloy are stable.

* In a phase diagram, for each change of phase, adequate time is allowed for the change to complete so that phase change takes place under equilibrium conditions, the phase diagram will be known as phase equilibrium diagram

* Equilibrium conditions are not generally attained during the solidification of welds and casting because due to fast cooling rates, adequate time is not available

limited by definite bonding surfaces (17)

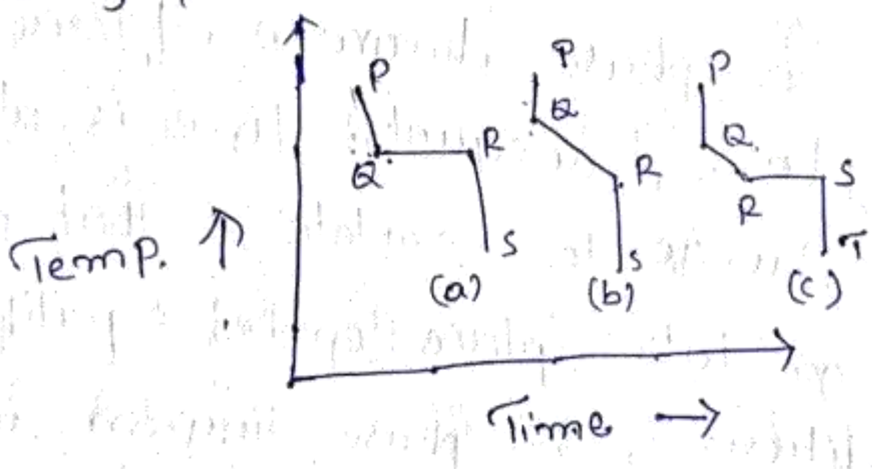
COOLING CURVES (OR) ISOMORPHOUS ALLOY SYSTEMS

A method to determine the temperature at which phase changes (from liquid to solid) occur in an alloy system consists of the following the temperature as a function of time as different alloys in the system are very slowly cooled.

The data obtained in the manner form a cooling curve for each of the alloys.

Types:-

1) Cooling curve for pure metal (or) compound



⇒ Liquid metal cools from 'P' to 'Q' first crystal begin to form at point 'Q'

⇒ ~~7 or~~ From Q to R the ~~ment~~ melt liberates latent heat of fusion in such amounts that the temperature from for each change of phase to complete (13)

LEVER RULE :-

* To determine the relative amount of two phases, erect an ordinate at a point on the composition which gives the total (or) overall composition of the alloy.
* The lever rule gives the fraction as two co-existing phases the tie line at the temperature of interest is treated as a lever arm, with the system fulcrum at the overall composition. It should be noted that tie-line rule gives the composition of the co-existing phases, whereas the lever rule gives the fractions (or amounts) of the phases.

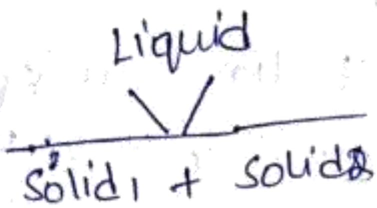
CORING

→ Coring or segregation is the non-uniform distribution of constituents in a metal usually a concentration of certain constituents and/or more impurites, arising during freezing and generally persisting throughout operations is known as coring or segregation.

EUTECTIC SYSTEMS

* In an eutectic reaction, when a liquid solution of fixed composition, solidfies at a constant temperature forms a mixture of two (or) more solid phases without an intermediate pasty state this process reverses on heating.

$$\text{Liquid} \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \text{Solid}_1 + \text{Solid}_2$$



* In eutectic system there is always as <u>specfic alloy</u> known as <u>eutectic composition</u> that freezes at a lower temperature than all other compositions.
* Under conditions approaching equilibrium (slow cooling) it i.e specific alloy freezes at a single temperature like a pure metal in other respects the solidification reaction of this composition is quite different from a mixture of two different solid phases

* At the eutectic temperature, two solid form simultaneously from a single liquid phases.
* The eutectic temperature and composition determine a point on the phase diagram called the eutectic point.

PERITECTIC REACTION

* It is the reaction that occurs during the solidification of some alloy where the liquid phase reacts with a solid phase to give a solid phase of different structure.
* The reaction revercs on melting (Heating)

$$\text{Liquid} + \text{solid}_1 \underset{\text{Heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \text{New solid}_2$$

Liquid + solid1

New Solid2

* Peritectic reaction is actually, just the opposite of the eutectic Reaction
* Assuming very slow rates of cooling, the peritectic reaction will occur only in those alloys

Equilibrium Diagram

* Equilibrium diagram is a graphical representation of different states of alloy system. It indicates the phases existing in the system at any temperature and composition.

Applications

1) To predict the safe temperature of heat treatment & working
2) To determine the number of phases, types of phases, composition of phases present in any given alloy at a specific temperature.
3) To calculate relative amount of the phases present in a two phase alloy.
4) To describe the freezing & melting of an alloy

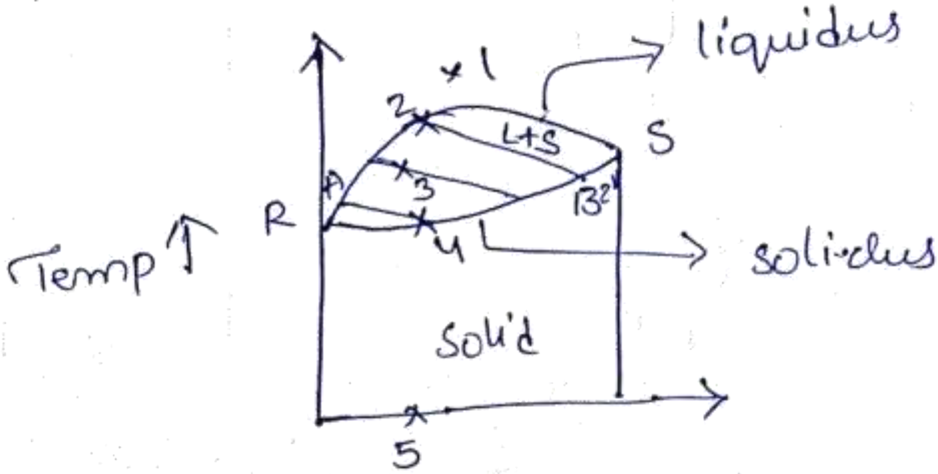
Isomorphous Alloy

There are the system in which two metals are completely soluble in liquid as well as solid state.

Examples

Cu-Ni, Au-Ag, Au-Cu, Mo-W,
Au-Ni, Bi-Sb etc..

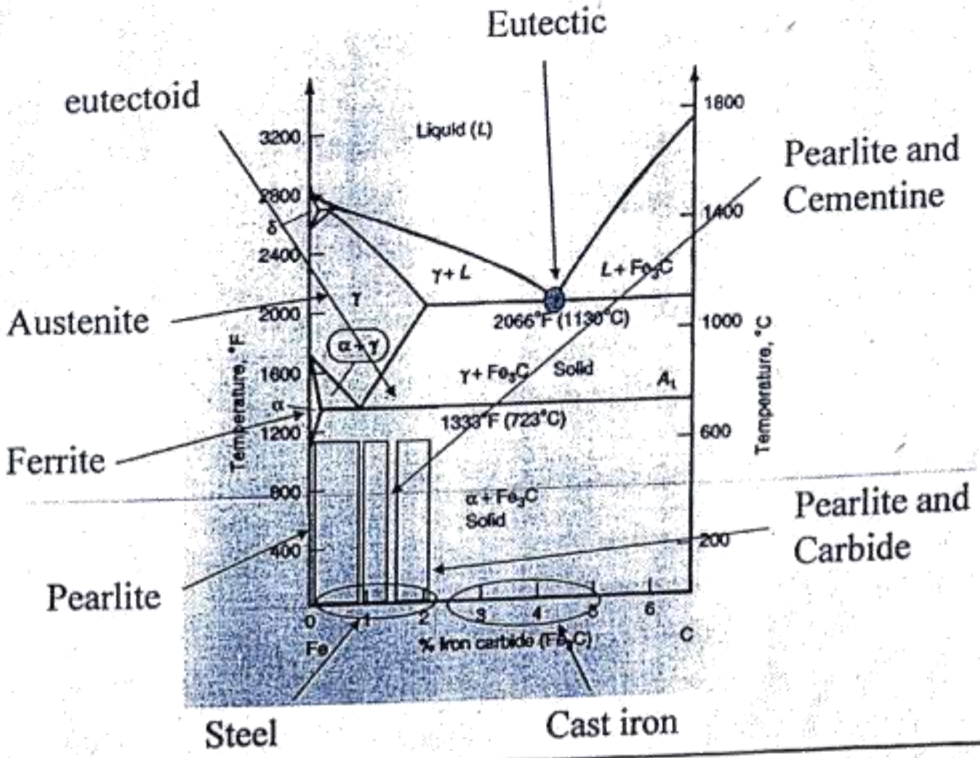
Let us consider the cooling of an alloy with x% of B from point 1 (liquid state) to point 5 (room temperature). P and Q are two metal whose melting temperature are R and S respectively



From point 1-2 there will be no change in the state i.e the alloy will be in liquid state. From point 2 the alloy starts solidify-ing.

The amount solid depends on the temperature i.e as temperature decreases the amount of solid increases and this stage continous upto point 4 where the alloy will be solid state from point 2-4 the average composi tion of the existing solid and liquid is given by the solidus and Liquidus lines, the amount of solid and liquid can be obtained by applying lever rule at a given temperature.

IRON IRON-CARBON DIAGRAM



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Outline

- Introduction
- Cooling curve for pure iron
- Definition of structures
- Iron-Carbon equilibrium phase diagram – Sketch
- The Iron-Iron Carbide Diagram - Explanation
- The Austenite to ferrite / cementite transformation
- Nucleation & growth of pearlite
- Effect of C %age on the microstructure of steel
- Relationship b/w C %age & mechanical properties of steel

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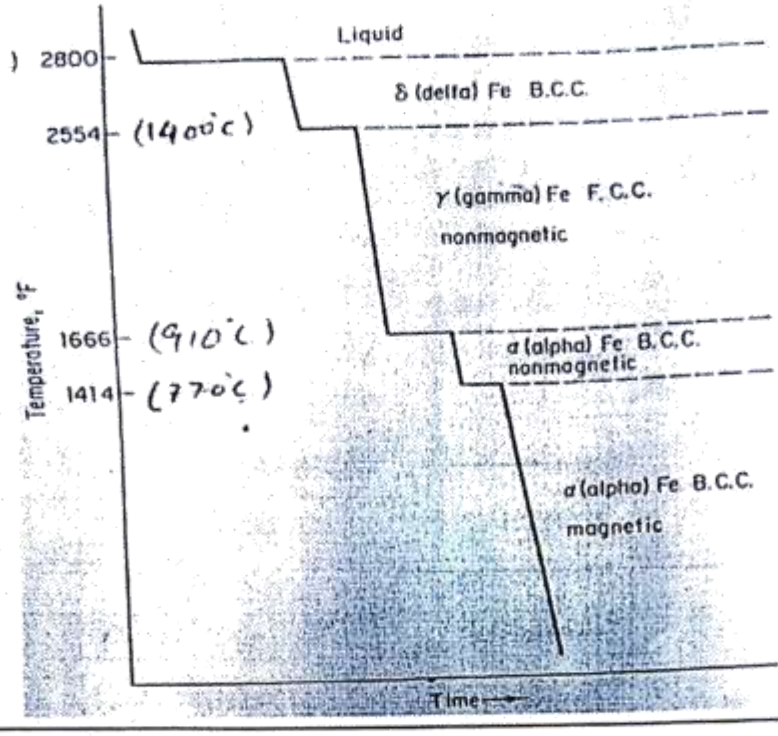
Cooling curve for pure iron



Definition of structures

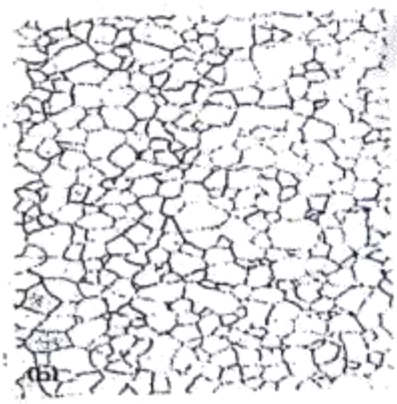
Various phases that appear on the Iron-Carbon equilibrium phase diagram are as under:

- Austenite
- Ferrite
- Pearlite
- Cementite
- Martensite*
- Ledeburite

Definition of structures

- **Ferrite** is known as α solid solution.
- It is an interstitial solid solution of a small amount of carbon dissolved in α (BCC) iron.
- stable form of iron below 912 deg.C
- The maximum solubility is 0.025 % C at 723°C and it dissolves only 0.008 % C at room temperature.
- It is the softest structure that appears on the diagram.

Definition of structures



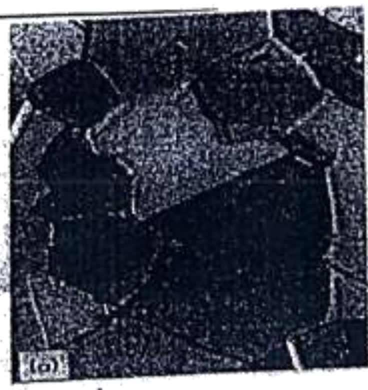
Ferrite

- Average properties are:
  - Tensile strength = 40,000 psi
  - Elongation = 40 % in 2 in;
  - Hardness > Rockwell C 0 or > Rockwell B 90

Definition of structures

- **Austenite** is an interstitial solid solution of Carbon dissolved in γ(F.C.C.) iron.
- Maximum solubility is 2.0 % C at 1130°C.
- High formability, most of heat treatments begin with this single phase.
- It is normally not stable at room temperature. But, under certain conditions it is possible to obtain austenite at room temperature.

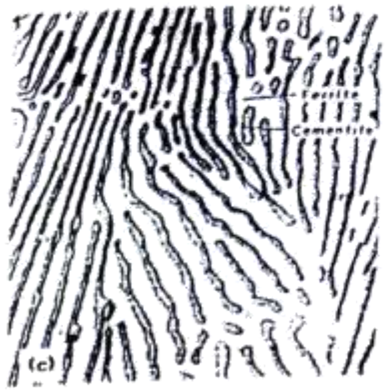
Definition of structures



Austenite

- Average properties are:
  - Tensile strength = 150,000 psi;
  - Elongation = 10 percent in 2 in.;
  - Hardness = Rockwell C 40, approx; and
  - toughness = high

Definition of structures



- **Pearlite** is the eutectoid mixture containing 0.80 % C and is formed at 723°C on very slow cooling.
- It is a very fine platelike or lamellar mixture of ferrite and cementite.
- The white ferritic background or matrix contains thin plates of cementite (dark).

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Definition of structures

Pearlite

- Average properties are:
  - Tensile strength = 120,000 psi;
  - Elongation = 20 % in 2 in.;
  - Hardness = Rockwell C 20, Rock-well B 95-100, or BHN 250-300.

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Definition of structures

- **Cementite** or iron carbide, is very hard, brittle intermetallic compound of iron & carbon, as Fe_3C, contains 6.67 % C.
- It is the hardest structure that appears on the diagram, exact melting point unknown.
- Its crystal structure is orthorhombic.
- It is has
  - low tensile strength (approx. 5,000 psi), but
  - high compressive strength.

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Definition of structures

- **Ledeburite** is the eutectic mixture of austenite and cementite.
- It contains 4.3 percent C and is formed at 1130°C.

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