Chapter 1

Structure and Properties of Materials

CHAPTER HIGHLIGHTS

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STRUCTURE OF MATERIALS

Crystallography

Arrangement and disposition of atoms with in a crystal is called structure

Atoms of a crystalline material is arranged in a definite geometrical order. When these materials solidify from other state, the atoms arrange themselves into specific positions in 3 dimensional space to form crystals. If the centres of these atoms in a crystal are joined, the lines joining form a 3 dimensional geometrical shape called **space lattice**. The smallest volume of this space lattice which properly represents the positions of atoms with respect to each other is known as a **unit cell**. Unit cells are the building blocks of a crystal. This is the simplest volume which completely fills the space and has the characteristics of the whole cell.

If the atoms in a crystal is replaced by smaller circles or points, a group of small circles or points is obtained. Each point has its surrounding identical to that of every other point. These points are called **lattice points**. Thus lattice points are corner points of unit cells.

There are seven types of **basic crystal systems**. They are

1. Cubic
2. Tetragonal
3. Hexagonal
4. Orthorhombic
5. Rhombohedral
6. Monoclinic
7. Triclinic

Bravais Lattices

According to Bravais there are 14 possible types of space lattices in the 7 crystal systems mentioned above. They are

1. Simple cubic lattice
2. Body centred cubic lattice
3. Face centred cubic lattice
4. Simple tetragonal lattice
5. Body centred tetragonal lattice
6. Simple hexagonal lattice
7. Simple orthorhombic lattice
8. End centred orthorhombic lattice
9. Body centred orthorhombic lattice
10. Face centred orthorhombic lattice
11. Simple rhombohedral lattice
12. Simple mono clinic lattice
13. End centred monoclinic lattice
14. Simple triclinic lattice

Metallic Structure

We have seen that there are 14 valid lattices and a crystal belong to any one of these. But it is found that most of the common metals have cubic or hexagonal structure only

Three most common crystal lattice structures are

1. Face Centered Cubic (FCC)
2. Body Centered Cubic (BCC)
3. Hexagonal Close-Packed (HCP)

In FCC structure, unit cell is a cube with one atom at each corner of the cube and one each face.

Examples are – Ca, Ni, Cu, Ag, Pt, Au, Pb, Al and alloys of these. They have good ductility and good electrical conductivity.

In BCC structure, atoms are present at all eight corners of the cube and another one at the body centre.

Examples are – Fe, Na, K, V, Mo, Ta, W

They have more tendency to deform plastically.

In HCP structure, atoms are at each corner of a hexagonal prism and one atom each at the centre of top and bottom faces. And three atoms in the mid plane.

Examples are – Be, Mg, Zn, Cd, Co, Ti

They have good ductility and can be easily deformed.

Imperfection in Crystal Structure of Metals (Defects)

Strength of a metal is always less than the value obtained by theoretical calculations. This is due to imperfections and defects in crystalline structure. The following are three types of important defects.

1. Point defects
2. Line defects
3. Surface defects or planar imperfections

Point Defects

Point defects take place due to imperfect packing of atoms during crystallization. Vibration of atoms at high temperature also cause point defects.

1. Vacancy defect
   When one or more atoms are missing from a normally occupied position, the defect is known as vacancy.
2. Interstitial defects
   When an extra atom occupies interstitial positions (voids) in the parent crystal, the defect is called interstitial defect.
3. Frenkel defect
   It is a combination of vacancy and interstitial defect. A missing atom responsible for vacancy occupies an interstitial position.
4. Substitutional defect
   When a foreign atom displace a parent atom, the defect is known as substitutional defect.
5. Schottky defect
   When a pair of positive and negative ions is missing from ionic crystal, the defect is known as Schottky defect. Due to this defect there is no change in the neutrality of the crystal.

Line Defects

The type of defects are due to dislocation or distortion of atoms along a line. Examples are

1. Edge dislocation
   When a half plane of atoms is inserted between the planes of atoms, the defect is called edge dislocation.
2. Screw dislocation
   This occurs when a part of the crystal displaces angularly. Magnitude and direction of edge dislocation is given by a vector called **Burger vector**.

Surface Defects

Surface defects or plane defects occur on the surface of a material. If happens due to imperfect packing during crystallization or defective orientation of the surface.

Grain Boundary Defect

Grains of different orientations separate the general patterns of the atoms exhibiting a boundary. This defect is called grain boundary defect.

Twinning: In twinning or twin boundary defect, atomic arrangement on one side of the boundary is a mirror image of arrangement of atoms on the other side.

Volume Imperfection

Volume imperfections are 3-dimensional imperfections inside the solids. The reasons are foreign particle inclusions region of non-crystallizing, pores etc.

Allotropic Forms of Materials

Some materials exist in more than one form depending up on temperature. They are called allotropic forms.

For example,

Cobalt

Below 420°C – HCP

470°C to 1495°C = FCC

Chromium

Below 20°C – HCP

20°C to 1799°C – BCC

Fe

Below 912°C – BCC

912°C to 139°C – FCC

In carbon steels, temperature ranges vary depending upon the carbon content. Carbon steel with 0.8% carbon has a BCC structure below 723°C.

Usually non-crystalline materials do not have lattice arrangement of their atoms. Such materials are known as amorphous substances. Some of the common examples of amorphous substances are rubber, transparent polymers, metallic glasses thermoset plastics etc.

PROPERTIES OF ENGINEERING MATERIALS

Engineering materials can be metalic or non-metallic. Mettalic materials may be ferrous or non-ferrous. Ferrous materials consist mainly of iron with comparatively small addition of other materials. Cast iron, wrought iron and carbon steels are examples.

Non-ferrous materials contain little or no iron. Examples are Aluminium, copper, zinc, tin, nickel, titanium etc.

Non-metallic materials include plastics, rubber, leather, wood, glass etc.

Types of Materials

Materials can be classified into three groups.

1. Isotropic material
2. Anisotropic material
3. Orthotropic material

A material that displays same elastic properties in all directions of loading is called isotropic material. The equation of strength and elasticity are based on this assumption. In these materials all planes are planes of symmetry. All metals are isotropic. Number of elastic constants are two only.

In anisotropic materials different property values are exhibited in different directions with respect to a set of reference axes. For these materials there are no planes of symmetry. Total number of elastic constants are 36 in which 21 numbers are independent.

Orthotropic material is a type of anisotropic material. It has got 3 orthogonal planes of symmetry. There are 12 elastic constants in which 9 are independent.

Stress–strain Diagram for Engineering Materials

When a body is subjected to forces it develops internal resisting forces. The resisting forces may be split into normal and parallel to a section. Resisting force parallel to the section is called shearing resistance. Intensity of resisting force normal to the section is called intensity of normal stress or simply the normal stress.

Normal stress is mathematically expressed as

$$\sigma = \lim_{\Delta A \to 0} \frac{\Delta R}{\Delta A}$$

$$= \frac{dR}{dA}$$

where R is the normal resisting force.

Similarly shearing stress

$$\tau = \lim_{\Delta A \to 0} \frac{\Delta Q}{\Delta A}$$

$$= \frac{dQ}{dA}$$

where Q is the shearing resistance.

When the body is subjected to forces, it undergoes changes in shape and size also.

It is seen that bars extend under tensile force and shorten under compressive force. The change in length per unit length is known as linear strain.

Thus linear strain $e = \frac{\Delta L}{L}$

Experiments has shown that for a body under the action of forces, the stress and strain has got certain relationship

Hooke's Law

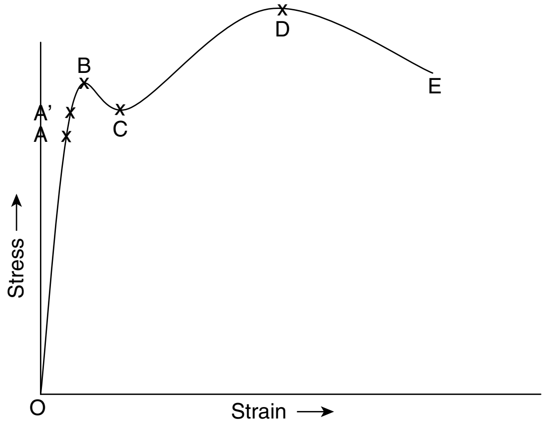
Robert Hooke, from his experiments concluded that stress is proportional to strain up to elastic limit. This is known as Hooke's law.

Thus $\sigma \propto e$

or $\sigma = Ee$

where E = constant of proportionality and is known as Young's modulus or modulus of elasticity.

Stress–strain Diagram for Mild Steel



When a mild steel specimen is subjected to tensile load and the stress-strain relationship is plotted, the following salient points are observed.

Limit of Proportionality (A)

Upto this point stress is proportional to strain.

Elastic Limit (A′)

This is slightly above A and up to this point the elasticity is maintained or the strain disappears completely and the original length is regained, when it is unloaded below this point.

Upper Yield Point (B)

When this point is reached stress starts reducing and extension increases or yielding of the material takes place.

Lower Yield Point (C)

At this point stress and strain increases again.

Ultimate Stress (D)

This is the maximum stress the material can resist. After this point cross sectional area reduces at a section (necking). Stress again reduces and strain increases.

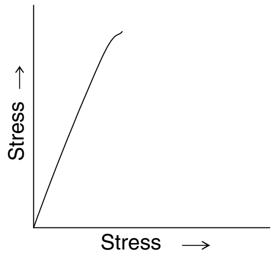
Breaking Point (E)

Stress at this point is called fracture stress. This is the point at which the specimen breaks.

The region C to D is called work hardening or strain hardening region.

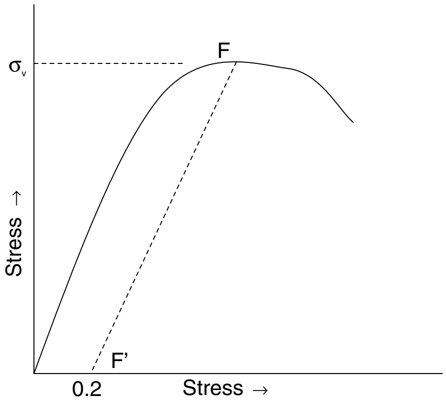
Stress-strain Relationship in Brittle Materials (example-cast iron)

Stress-strain relationship for a brittle material like cast iron is shown in the figure.



In this case there is no appreciable change in rate of strain. There is no yield point. There is no necking and ultimate point and breaking point are same.

Stress-strain Relationship in Aluminium and High Strength Steel

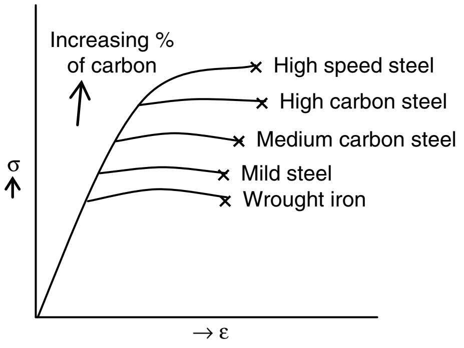


In these materials there is no clear cut yield point. At ultimate stress necking takes place and breaking occurs at a lower stress as in the case of mild steel.

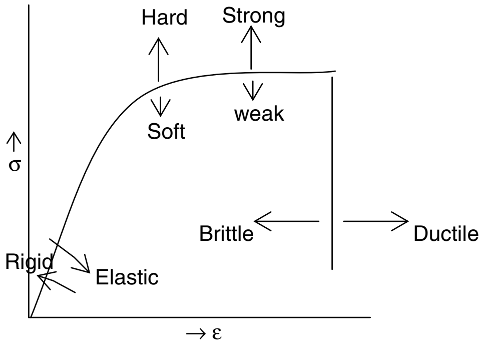
The stress at which 0.2% permanent set is there is treated as yield stress.

(The percentage of permanent strain left in the material when the material is unloaded after loading above elastic point is called permanent set.)

Effect of Carbon Percentage on Stress-strain Diagram of Steel



Characteristic Changes in Properties of Materials Showing Different Stress-strain Relationships



Properties

1. Strength

Resistance offered by a material on application of external force is called strength. Or it is the ability to sustain loads without distortion. It can be tensile, compressive, shear, bending or torsional.

2. Hardness

It is the resistance of the material to mechanical indentation. It is the general indication of the strength as well as resistance to wear and scratching.

Diamond is the hardest known material.

3. Toughness

It is the ability of a material to with stand suddenly applied load and thus absorb a certain amount of energy without failure.

It depends both on strength and ductility. Alloy steels with good toughness are used for manufacturing of cutting tools like milling cutters gears subjected to impact loads etc.

4. Ductility

Ductility is the property of a material which permits permanent deformation before fracture by stress in tension. It is the extend to which a material can sustain plastic deformations under tension, before rupture gold is most ductile of all metals.

5. Brittleness

Brittleness is the inability to undergo plastic deformation. Materials that under go very little plastic deformation is called brittle. If the percentage of elongation is less than 5% the material is treated as brittle. If it is more than 5% it is ductile. Cold shortness is the brittleness that exist below recrystalisation temperature. Red shortness is the brittleness of steel at high temperature caused by the formation of iron sulphide.

6. Malleability

Malleability of a material is its ability to be flattened in to thin sheets without cracking in the cold state under compressive loading (pressing, rolling, hammering, etc.)

7. Resilience

It is the capacity of a material to absorb energy elastically. Energy stored is released on removal of the load. It is important property desirable for shock absorbers and springs.

8. Stiffness

It is the resistance of a material to elastic deformation or deflection.

9. Fatigue

Under fluctuating or repeated loads, a material tend to develop a characteristic behavior which is different from that under steady loads and then the material is said to be another fatigue. Due to fatigue, material will fail at loads less than loads at normal conditions. The maximum stress at which even a billion reversal of stresses cannot cause failure is called endurance limit.

10. Creep

Creep is the slow plastic deformation of a material under constant stresses usually at high temperature.

11. Elasticity

It is the ability of a material to return to original shape from the deformed shape caused by an applied load, up on the removal of the load.

12. Plasticity

Plasticity is the ability of the materialto undergo some degree of permanent deformation without rupture.

Isotropy

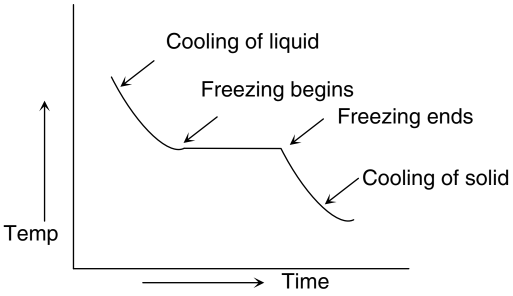
If a material has same elastic properties in all direction, it is an isotropic material.

Anisotropy

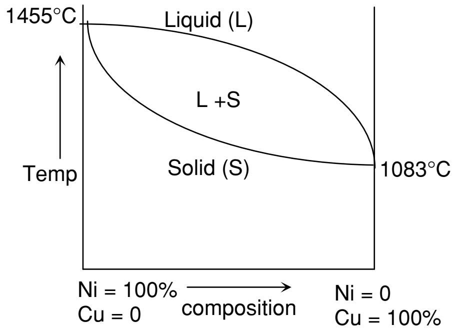
If elastic propertries are different in different directions it is anisotropic.

EQUILIBRIUM DIAGRAMS

Pure metals have clearly defined freezing/melting point, solidification/melting lakes place at constant temperature. But in the case of an alloy solidification/melting takes place over a range of temperature.



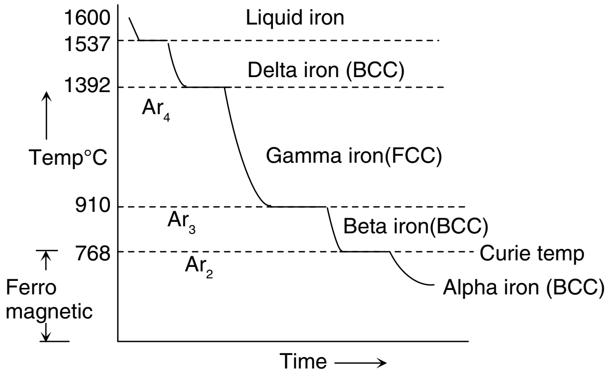
Cooling curve of a pure metal



Cooling curve of an alloy (Ni + Cu)

Allotropic Forms of Steel

For metals with different allotropic forms the curves are not as simple as shown above. The transformation from one allotropic form to another takes place at a constant temperature just the same way as in the case of liquid – solid transformation. Iron exist in different allotropic forms depending up on temperature. Cooling curve for pure iron is shown in this figure.



Cooling curve for pure iron

The first horizontal step at 1537°C represents liquid to solid transformation with evolution of heat. The mixture consist of liquid plus delta iron solid solution. At temperature 1392°C delta iron transforms to a new allotropic form gamma iron The next step is at 910°C where Gamma iron transform to Beta iron. At the last (4th) step at 768°C Beta iron is transformed to Alpha iron. Gamma iron is of a FCC structure and other forms are of BCC structure. Alpha iron acquires pronounced ferromagnetic properties Beta and other forms are para magnetic.

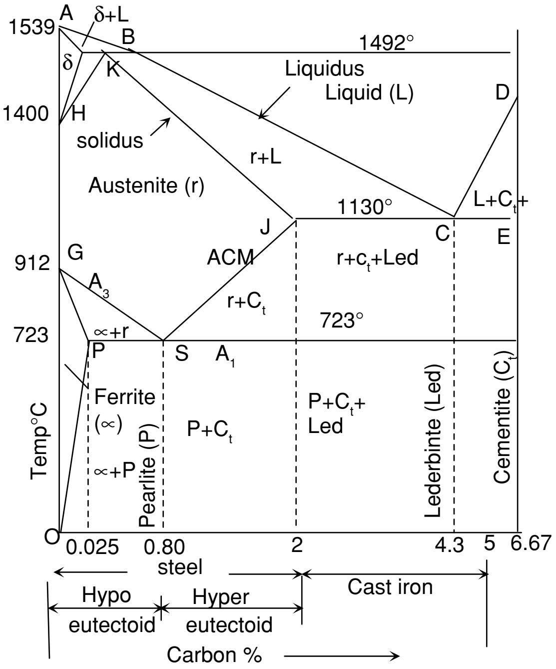
Since space lattice does not change in the Alpha to Beta transformation beta iron is regarded as paramagnetic state of alpha iron. Thus there are only two main allotropic form – Alpha iron and Gamma – iron.

Critical Points

The points where structural changes occur are known as critical points. On a cooling curve it is represented by Ar_4, Ar_3 and Ar_2 at temperature 1392°C, 910°C and 768°C respectively. On a heating curve these points are represented by Ac_4, Ac_3 and Ac_2

Absolutely pure iron is very difficult to obtain. In this state it is a soft and very plastic material of not much use in engineering application. But it can be alloyed with many elements. Alloys of iron and carbon are most widely used in engineering.

Iron–Carbon Equilibrium Diagram or Phase Diagram



Iron-carbon phase diagram

L – Liquid (Molten alloy)
δ – Delta iron
γ – Austenite (gamma iron)
C_t – Cementite (Fe_3c)
α – Alpha iron (Ferrite)
P – Pearlite
Led – Lederburite

Iron-carbon equilibrium diagram is obtained on plotting the critical points of different iron-carbon combinations. Carbon in equilibrium does not appear as free carbon (graphite) but appear in the form of iron carbide (Fe_3C) containing 6.67% carbon on the right. Cementite is a chemical compound of iron and carbon and may form up on rapid cooling of iron-carbon melt from high temperature. It is brittle, weak in tension, strong in compression and is the hardest of any material in the equilibrium diagram. It will be observed from the figure that carbon is soluble in μ - iron to a maximum of 0.025% at 723°C (point P). At room temperature solubility is only 0.008%. Alpha iron is commonly called ferrite or more accurately Alpha–ferrite. It is the softest.

The temperature 723°C is called **curie temperature**. Below curie temperature steel acquires ferromagnetic properties.

Critical Temperatures

A_1 is the temperature at which Pearlite changes to Austenite. This transformation occurs at a fixed temperature of 723°C irrespective of the composition of alloy. A_1 represents the lower critical temperature.

A_3 is the temperature at which last traces of ferrite changes to Austenite and the alloy becomes 100% austenite. A_3 vary from 723°C to 912°C. Depending up on the carbon content. This represents the upper critical temperature.

Acm is the temperature at which last traces of cementite changes to austenite and the alloy become completely austenite. Depending up on Carbon content this temperature varies from 723°C to 1130°C. This also is upper critical temperature. During cooling Acm denotes the temperature at which iron carbide is first rejected from austenite instead of ferrite.

Referring to the iron-carbon phase diagram, the solidification, of the liquid iron and carbon melt begins along the liquidus ABCD. Along AB the crystals of solid solutions of carbon in delta iron are separated from the liquid. Along the line BC crystal of austenite are separated. Complete solidification of these alloys takes place along the solidus line HKJCE. All the liquid is completely solidified at 1130°C. At the same time crystals of austenite containing 2% carbon and cementite containing 6.67% carbon get separated from it. The solidification of alloys containing 4.3% to 6.67% carbon begins along the line CD with the separation of primary cementite from the melt.

Eutectoid Point

Point S is called eutectoid point. At the temperature of 723°C eutectoid reaction occurs. i.e, formation of two solids occur from a single solid. Simultaneous formation of ferrite and cementite occurs from austenite at the temperature of

723°C and composition of 0.80% carbon. Nearly 12% of iron carbide and slightly more than 88% ferrite are formed at this condition. The intimately mixed, lamellar mixture is composed of alternate layers of ferrite and cementite. This microstructure is called Pearlite.

The eutectoid reaction can be written as

$$\text{solid } A \xrightleftharpoons[\text{Heating}]{\text{Colling}} \text{solid } B + \text{solid } C$$

or

$$\underset{(\gamma\,0.8\%\text{C})}{\text{Austenite}} \xrightleftharpoons[\text{Heating}]{\text{Cooling}} \underset{(0.02\%\text{C})}{\text{Ferrite}} \quad + \underset{(6.67\%\text{C})}{\text{Cementite}}$$

The alloy containing 0.8% carbon is called eutectoid steel. If carbon content is greater than 0.8% austenite transforms into Pearlite and cementite.

Maximum solubility of carbon in gamma iron is 2% (point J).

Eutectic Point

Point C is the eutectic point at which the two constituents solidifies simultaneously. It has the lowest liquidus temperature (1130°C) and carbon content is 4.3%. In the eutectic reaction the molten alloy solidifies into a mixture of two solids (ausentite and cementite), known as *Lederburite*. At eutectic point only lederburite is formed. (Lederburite is $\gamma-Fe_3C$ eutectic matrix) At higher carbon content greater than 4.3% C, Fe_3C is embedded in the eutectic matrix.

The eutectic reaction can be written as

$$Liquid\ L \rightarrow solid\ A + solid\ C$$

$$or\ Liquid \xrightleftharpoons[1130^\circ C]{43\%C} Austenite(\gamma) + Cementite[Fe_3C]$$

At eutectic point liquid phase coexist with two solid phases

Iron-carbon alloys containing more than 2% carbon is known as Cast iron.

Less than 4.3% carbon is hypoeutectic and more than 4.3% and up to 6.67 they are hyper eutectic cast irons.

Peritectic Point

Point K is called the peritectic point.

Peritectic reaction can be generally written as

$$\text{Solid B} + \text{Liquid L} \rightleftarrows \text{solid A}$$

Peritectic reactions takes place along the horizontal line at 1492°C. Liquid + δ iron transforms to γ – iron at point K. Maximum solubility of carbon in δ – iron is 0.09% but in fcc r-iron the solubility of carbon is much greater.

Peritectoid Point

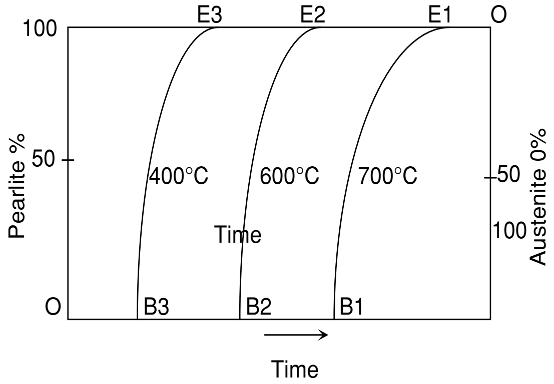
In peritectoid reaction two solid phases change to one solid phase and the corresponding point is called peritectoid point.

TTT Curves

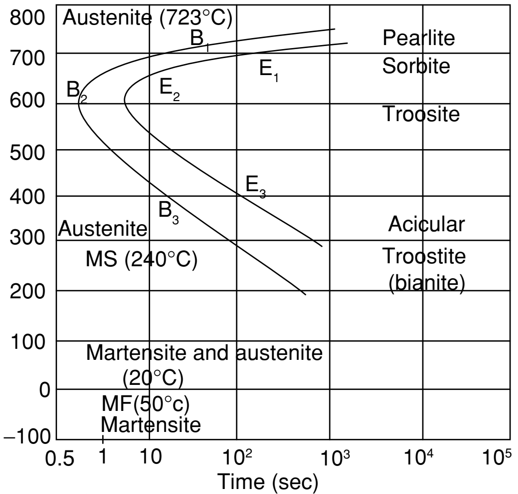
Iron-carbon equilibrium diagram, provides a complete picture of phase changes, corresponding microstructure and temperature under equilibrium conditions. The effects of different cooling rates are not revealed in this diagram. In different heat treatment process, transformation of austenite depends upon the cooling rate. A time based equilibrium diagram explains the transformation with respect to cooling rates. The basis of heart treatment of steel is time, temperature and transformation. Time temperature and transformation diagram (TTT diagram) depicts these variables.

To construct these curves a number of small specimens of steel are heated above critical points and these are then rapidly cooled to a number of temperatures and held at these temperatures for different periods of time until austenite is completely decomposed. At any given time, the percentage of austenite and pearlite are also noted by studying the structure. The transformation of austenite at a constant temperature starts only after an 'incubation period'.

First, curves for constant temperature are drawn with time as x-axis and percentage composition of pearlite and austenites on y-axis.



From the above curves, the TTT curves are constructed.



TTT Diagram

Austenite decomposes to pearlite at near about 700°C. Troosite is formed at 500 to 550°C. Bianite is formed at 550 to 200°C. Martensite transformation starts (point Ms) at 240°C. and finishes (point MF) at 50°C. These points are not affected by cooling rate. But their positions depend upon chemical composition of steel. TTT diagram is also known as isothermal (IT) diagram or C-curve. or S-curve based on its shape.

Manufacturing of Cast Iron, Wrought Iron and Steel

Cast iron, steel and wrought iron are manufactured from pig iron which contains 4.5 to 6.67% carbon. Pig iron is obtained from chemical reduction of iron ore in blast furnace. The process is known as smelting.

Cast iron which contains 2 to 6.67% carbon is produced in cupola by remelting pig iron.

Commercial cast iron contains 2.5 to 4% carbon. Cast iron is very brittle and has low ductility.

Wrought iron is a mixture of pure iron and 1-3% slag. It contains traces of carbon (less than 0.05%), silicon, manganese, sulphur and phosphorus. For production of wrought iron pudding furnace or Aston or Byers process is used.

Wrought iron is ductile and soft and is very suitable for forging and forge welding. Strength of wrought iron can be increased by cold working or alloying with constituents like nickel (1.5 to 3.5%)

Steel contains iron and less than 2% carbon. Steels can be classified as plain carbon steels, alloy steels, special alloy steels and cast steels. Plain carbon steels contain iron and carbon and impurities like silicon, manganese, sulphur and phosphorus.

Depending upon the carbon content, plain carbon steels are classified as

1. Low carbon or mild steel
   (0.05 to 0.3% C)
2. Medium carbon steel
   (0.3 to 0.6% C)
3. High carbon steel
   (0.6 to 1.5% C)

Sulphur and phosphorus are harmful impurities in steel causing brittleness. Silicon and manganese are deoxidizers and purify the steel.

Alloy steels contain specially introduced alloying elements which modifies or enhances the properties of plain carbon steel.

Most frequently used alloying elements are chromium (Cr), Nickel(Ni), Manganese (Mn), silicon (Si), Molybdenum (Mo), Vanadium (Va), Tungsten (W), copper(Cu) and aluminium(Al).

Steel is produced using Bessemer process, open hearth process or electric furnace.

Types of Cast Iron

Cast iron is the cheapest cast material. In molten state, it flows readily. Plain cast iron is strong in compression and weak in tension and shear. It has a very good damping capacity. Properties of cast iron can be varied by the addition of alloying elements and heat treatment. Main types of cast iron are

1. Gray cast iron
2. White cast iron
3. Malleable cast iron
4. Ductile cast iron
5. Chilled cast iron
6. Alloy cast iron
7. Meehanite cast iron
8. Mottled cast iron

1. Gray cast iron

It is the most widely used cast iron. It contains 2.5 to 3.75% carbon and up to 2.5% silicon.

In gray cast iron, carbon is in the form of graphite flakes. Gray cast iron is soft and only moderately brittle. The free graphite in its structure acts as a good lubricant and increases the machinability.

2. White cast iron

In white cast iron, carbon is in the form of cementite (Fe_3C) It contains carbon up to 2.5% and silicon below 1.5%.

It is very hard and brittle and has very limited applications.

3. Malleable cast iron

Malleable cast iron is produced by heating white cast iron for a prolonged period of time to a temperature of 850 to 1000°C and after that by cooling at a slow rate. In this process cementite decomposes to ferrite. Silicon content is kept less than 1% to avoid graphitization. Method of production used is called Blackheart method and the cast iron obtained is ferritic malleable cast iron.

In another method called white heart method pearlitic malleable cast iron is produced.

4. Ductile cast iron or spheroidal cast iron

In ductile cast iron carbon is precipitated as spherical nodules of graphite. It is also called **nodular** cast iron. It is of high grade in comparison to malleable cast iron. To produce ductile cast iron, small amounts of special alloys containing magnesium (Mg) or cerium (Ce) is added to desulpherised molten cast iron.

Ductile iron possesses good fluidity, high strength and ductility. It is tougher and less porous than gray cast iron.

5. Chilled cast iron

Chilled cast iron is made by using ‘chills’ in the moulds which promotes rapid cooling of the cast iron. On rapid cooling of the molten metal in the mould, a hard, wear resistant surface of 1 mm to 2 mm thickness consisting of white cast iron is produced. The material inside is only gray cast iron.

6. Alloy cast iron

Cast iron added with alloying elements is called alloy cast iron. Commonly used alloying elements are nickel, copper, chromium, molybdenum, vanadium and boron. Alloying elements are added to control graphitization and to improve mechanical properties such as improved resistance to heat, corrosion, wear and brittle fracture. Castability and machinability are also improved by the addition of alloying elements.

7. Meehanite cast iron

It is a patended product produced by the addition of calcium-silicon alloy called calcium silicide. It acts as a graphitizer and produces fine graphite structure with excellent mechanical properties. Gray cast iron with low silicon and moderately low carbon content is used for the production of meehanite cast iron.

8. Mottled cast iron

Mottled cast iron is produced by heating cast iron to red hot with powdered red hematite. The product has outer layers of white cast iron with core of gray cast iron. Toughness of cast iron is increased by this process.

Heat Treatment of Metals

Heat treatment means heating the metal to various definite temperatures, holding these for various time durations and cooling at various rates. In these controlled heating and cooling, of nature and distribution of the micro constituents, grain size etc changes. The main purpose of heat treatment operation is the control of properties through the alteration of structure of the metal or alloy.

VARIOUS HEAT TREATMENT PROCESSES

Annealing

Anealing means heating the metal to a temperature slightly above the upper critical temperature and then cooling slowly, usually in the furnace itself. Purpose of annealing is:

1. To refine grain structure
2. To relieve internal stresses and
3. To reduce hardness. After annealing ductility, machinability etc are improved.

Generally annealing is a stress relieving and softening process.

Full Annealing

It removes all structural imperfections by complete recrystalisation, In this process steel is heated 50° to 60°C above the upper critical temperature for hypo-eutectoid steel and by the same temperature above the lower critical temperature for hyper–eutectoid steel. Metal is held at this temperature for a sufficient time so that proper structure changes takes place. The rate of cooling varies from 30 to 300°C.

Normalising

In the normalized process, metal is heated to a point 40° to 50° above its upper critical temperature, held at that temperature for a short duration and cooled in still air at room temperature. The purpose of normalizing is

1. to elimimate coarse grain structure produced during forging, rolling etc
2. to remove internal stresses
3. to improve certain mechanical and electrical properties (improves corrosion resistance since it is cooled in still air sufficient oxidization would have taken placed. Further it resists corrosion during application.)

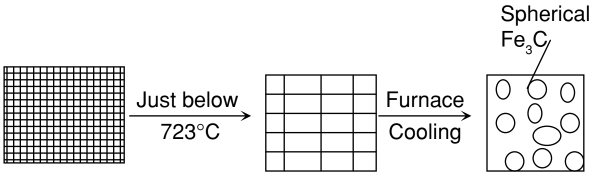
Spherodizing and Hardening

In this process steel is heated to a temperature above, critical point, held at this temperature for a considerable time, depending up on its thickness and then quenched (rapidly cooled) in water, oil or molten salt baths. For hypo euctoid steels heating is done 30°C to 50°C above lower critical temperature.

Spherodisation

It happens generally in steels with carbon percentage between 0.6 and 1.2

The process of obtaining spherical grains of F_3C in steel in the process of annealing is known as Spherodisation. Spherical grains offer low Coefficient of friction against the tool bit used to perform machining. Therefore spherodising improves machinability.



Purpose of hardening is to increase wear resistance and to make it suitable for cutting tools etc.

Hardening of steel is accompanied by development of high internal stresses and brittleness. So hardening is followed by the process tempering. After hardening and tempering steel acquires higher strength hardness and ductility.

Sorbite, Troostite, Bainite and Martensite

Depending upon the rate of cooling austenite transforms various structures such as sorbite, Troostite, Bainite and martensite.

At very slow rate of cooling austenite transform to a mixture of ferrite and cementite called Pearlite.

On increasing the rate of cooling Sorbite is formed at about 600°C. Sorbite is fine pearlite which is harder.

If steel is cooled at a faster rate Troostile is formed at about 500–550°C. Troostite is extremely fine Pearlite which is still harder.

If temperature is lowered to 220°C acicular (needle like) troostite is formed. This is known as Bainite.

If steel is cooled at a very high rate so that austenite does not have time to decompose in to sorbite or troostile it is transformed in to a new acicular form called Martensite. It is very hard and brittle (BHN 650 to 750) and ferromagnetic.

Critical rate of cooling is the minimum rate of cooling at which the austenite is transformed In to marten site alone.

Tempering

Fully hardened steel is unable to with stand impact loads. Therefore some of the hardness and strength is sacrificed in a compromise to gain sufficient ductility and toughness. This is accomplished by tempering.

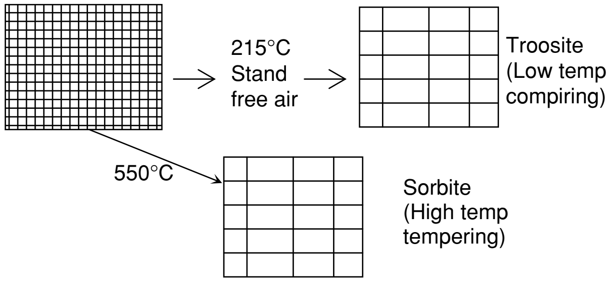
Tempering consists of

1. Heating the hardened steel to a temperature below the critical temperature
2. Holding it at the temperation for a specified time and
3. Slow cooling

As tempering is done at a lower temperature all the hardness is not lost.

Tempering is carried out to make steel tough and to resist shock and fatigue, to remove internal stresses, to stabilize the structure and to decrease hardness.

Tempering is carried out in liquid such as oil, salt or lead. Bath is heated to an adequate predetermined temperature and metal is immersed in this bath for a predetermined length of time. After that metal is removed and allowed to cool to room temperature.



$(\text{Hardness})_M > (\text{Hardness})_T > (\text{Hardness})_S$
$(\text{Grain size})_M < (\text{Grain size})_T < \text{Grain size})_S$

Hardening Methods

Hardening methods consist of:

1. Conventional or continuous or quench hardening
2. Quenching in two media
3. Stepped quenching
4. Interrupted quenching or martempering
5. Isothermal quenching or austempering and
6. Surface hardening

In conventional hardening, quenching is done in a single medium (Rapid cooling by immersing in a liquid medium is called quenching) This is the most commonly used method. Other methods are used for materials of intricate shape and when it is necessary to reduce distortion.

When quenching in two media is used, first liquid is usually water. Cooling is done in the first quench up to temperature of 300°C to 400°C and then quickly transferred to the second liquid(for example oil) and allowed to cool to room temperature.

Stepped quenching is also done in two stages. The first medium has a temperature of 150°C to 300°C above the point of formation of martensite. The part is held in this medium until the part attain the temperature of the medium through out its cross section. Usually the first medium is molten salt. Then it is transferred to the second medium usually an oil bath, where it is cooled to room temperature.

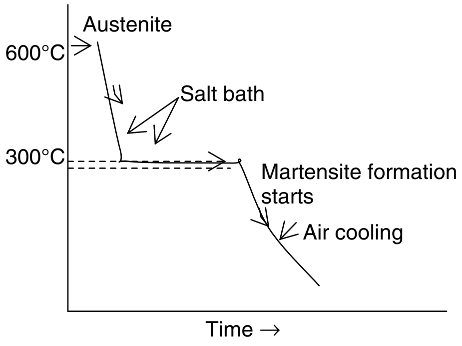
Interrupted Quenching or Martempering

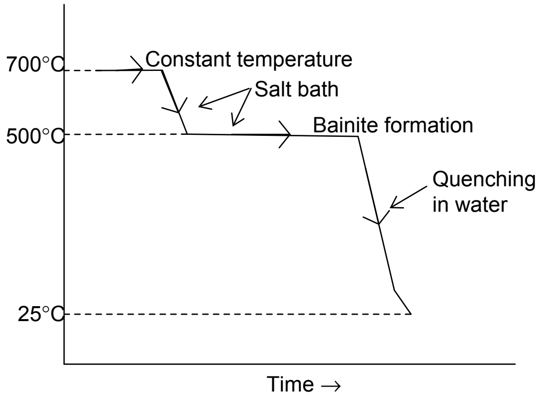
It is a modification of a stepped quenching method. Here second medium is still air and allowed to cool there to room temperature. Here the martensite formation takes place at a lower cooling rate. Therefore internal stresses are minimized.

Isothermal Quenching or Austempering

This process also is similar to martempering but the holding time in the salt bath above the martensitic temperature has a longer duration. The bath temperature is 300°C to 550°C. Longer holding time leads to isothermal transformation of austenite to bainite. Then the steel is quenched in water to room temperature. Here the residual stresses are substantially reduced.

The difference between martempering and austempering is illustrated in the figures given below.





Austempering

Surface hardening: It is a selective heat treatment process in which high hardness is imparted to thin surface layer of the work. This becomes necessary for parts, subjected to heavy impact and fatigue loads such as worms, gears, spindles, Cam shafts etc. where hard and wear resistant surface and a soft tough core is necessary. Low carbon steels having up to 0.2% carbon are subjected to chemical treatment process (case hardening) such as carburizing, Nitriding, Cyaniding etc. Steels with higher percentages of carbon are subjected to surface hardening methods in which only the surface layers of the work are heated and then quenched in some medium. Two methods used are

1. Electric induction surface hardening process
2. Flame hardening

Carburising

A low carbon steel cannot be hardened appreciably by the hardening process.

Surface of such steels are enriched by carbon before hardening and quenching. This is achieved by carburizing process.

The specimen along with a carbonaceous material such as charcoal is packed in a sealed container and kept in a furnace. The pack is heated to a temperature between 800 to 900°C and held for a period of 4 to 20 hours. Carbon monoxide is formed with the small amount of oxygen present. Carbon of carbon monoxide is diffused in to the metal surface releasing oxygen. This oxygen again reacts with carbon and carbon monoxide is formed and the process is repeated. As time progress metal surface gets enriched with carbon. This process is known as pack carburizing. The amount of carbon diffused into steel depends on the carburizing temperature and time. The process of carburizing is by atomic diffusion.

Another type of carburizing is gas carburizing. Gases such as natural gas propane, or methane is used instead of charcoal. Gas carburizing has better control of surface carbon and case depth than in pack carburizing.

Cyniding or Liquid Carbon Nitriding

In this process carbon and nitrogen are added to cases of metals. The piece of low carbon steel immersed in a bath of cynide salt (sodium cynide, sodium chloride and sodium carbonate in equal proportions.) of temperature 850°C to 950°C for about 15 to 20 minutes. Then it is quenched in water or oil. Carbon monoxide and nitrogen from the cynide bath behave as active diffusing agents in hardening the surface.

Nitriding

In this method nitrogen gas is used for obtaining hard surface of steel. This process is commonly used for steels which are alloyed with chromium, molybdenum, aluminium manganese etc. Steel articles well machined and finished are placed in a container through which ammonia in circulated. Nilriding process is generally done in electric furnace where temperature is maintained in the range 450 to 550°C. Ammonia gas when passing through the steel articles gets dissociated and nascent nitrogen is formed. Nascent nitrogen reacts with the surface of the articles forming nitrides which is very hard. Surface hardness up to depth of 0.8 mm is obtained.

Induction Hardening

This method is similar to flame hardening. But heating of the surface is achieved by electromagnetic induction. The work piece is enclosed in the magnetic field of an alternating current of high frequency (10 kHz to 2 MHz) current conductor (Induction block) Heating effect is due to the induced eddy currents and hyrterisis loses in the surface of the material. The induction block has water connections and numerous small holes on its inside surface. As soon as surface reaches proper temperature, it is automatically spray - quenched under pressure.

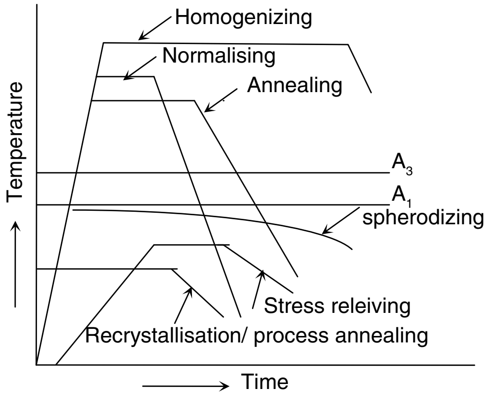
This process is very rapid and takes only few seconds to heat steel to a depth of 3 mm. The time varies depending upon frequency, power input, depth of hardening required etc.

Flame Hardening

Some times full case hardening of an article will not be required. Only the areas subjected to wear, abrasion or shocks are to be hardened. Such local hardening can be achieved by flame hardening. These areas are heated by a oxy - acetylene fame above its critical temperature. Heated portions is immediately quenched by means of spray of water. Since heating is localized stresses are not developed. So disortiuons and cracking are reduced.

Spherodizing (Spherodize Annealing)

High carbon hardened steel contains grains having sharp corners, which make the steel brittle. Spherodizing is the heat treatment process that produces a rounded or globular form of Carbide. Low carbon steels may be speroidized to improve strength before subsequent heat treatment. High carbon steels may be spherodized to improve machinability and toughness. The process involves heating the steel slightly below the critical temperature, holding at this temperature for a period of time and then letting them cool in the furnace. Holding time depends up on the thickness of metal and carbon content. More the percengage of carbon, longer will be the time required to complete sperodization.



Full Annealing

The process of annealing in which the metal is heated above the upper critical temperature, is held there until the temperature of work piece is uniform through out, and finally cooling at a slowly controlled rate so that temperature of the surface and that of the centre of the work piece is approximately same is called full annealing.

The process wiped out all traces of previous structure, refines the crystalline structure, soften the metal and relieves the previously set up internal stresses.

Process Annealing or Recrystallisation Annealing

Involves heating the steel to recrystallisation temperature, holding at this temperature for a prolonged period and slow cooling.

(Recrystallisation temperature = 0.4 × melting point of the metal)

Work hardened steels can be softened by this method.

Iso Thermal Annealing

When ordinary annealing process is incapable of reducing hardness of an alloy steel to a sufficient degree, isothermal annealing is employed. Here heating and cooling is done in two steps. First the steel is heated above critical temperature and held for sometime at the temperature. Austenite is formed at this stage. Then steel is rapidly cooled to 50° to 100°C below point A1 and held at this temperature until austenite is completely decomposed to form pearlite. Then steel is cooled in still air. Decomposition of austenite takes place at constant temperature. So it is called isothermal annealing.

Diffusion Annealing or Homogenising

In-homogeneity due to development of dentritic segregations in castings and ingots can be eliminated by diffusion annealing.

In this process the article is heated to a very high temperature and held there for a prolonged period, cooled with the furnace to 800°C–850°C. and finally cooled in still air. A coarse grain structure is obtained and composition becomes more uniformly. After homogenizing a full annealing treatment is required.

Effect of Alloying Elements in Steel

1. **Chromium (Cr)**
   Improves resistance to corrosion and oxidation
2. **Nickel (Ni)**
   Improves tensile strength and toughness.
3. **Manganese (Mn)**
   Imparts wear resistance
4. **Silicon (Si)**
   Added as a deoxidizing agent.
5. **Molybdenum (Mo)**
   Imparts hardenability.
6. **Vanadium (V)**
   Improves grain distribution.
7. **Tungsten (W)**
   Imparts red hardness
8. **Cobalt (Co)**
   Increases hot hardness
9. **Copper (Cu)**
   Lowers critical temperatures
10. **Aluminium (Al)**
    Deoxidises efficiently
11. **Titanium (Ti)**
    Increases abrasion resistance.
12. **Phosphorous (P)**
    Enhances machinability

Composition and Applications of Some Alloy Steels

Alloy steel	Composition percentage	Application
High carbon tool steel	C 0.8 to 1.3 Si 0.1 to 0.4 Mn 0.15 to 0.4 rest Fe	Milling cutters, turning tools
Low alloy carbon steel	C 1.2, Mn 0.3 to 0.7 W 2.75, Mo 0.4 S 0.3, rest Fe	For high temperature operation
18-4-1 High speed steel (HSS)	W 18, Cr 4, V 1 C 0.6 to 0.8 Rest Fe	High speed milling, drilling and turning tools

Composition and Application of Some Non-ferrous Alloys

Alloys	Composition percentage	Application
Copper Alloys		
Yellow brass (Muntz metal)	Cu 60, Zn 40	For hot working by rolling, extrusion and stamping
Leaded brass	Cu 62.5, Zn36 Pb 1.5	For plates, tubes etc
Phosphor bronze	Cu 87 – 90, Sn 9 – 10, P 0.1 – 0.3	For bearings, worm wheel, gears etc
Gun metal	Cu 88 Sn 10, Zn 2	For boiler fittings bushes, bearings etc
Aluminium alloys		
Duralumin	Cu 3 – 4.5 Mn 0.4 – 0.7 Mg 0.4 – 0.7 Rest Al	Automobile and air craft components
Y-alloy (Copper Aluminium alloy)	Cu 3.5 – 4.5 Mn 1.2 – 1.7 Ni 1.8 – 2.3 Si, Mg, Fe 0.6 each rest Al	Aircraft engines for cylinder heads and piston
Magnessium alloy	Al 7.5, Zn 2, Mn 0.3, Rest Mg	For air craft and automobile parts
	Common non-ferrous alloys	
Invar	Ni 36, Fe 64	Precision measuring instruments
Nichrom	Ni 80, Cr 20	Thermocouple, strain guage
Maganin	Cu 87, Mn 13	Resistor strain guage
Constantan	Cu 60, Ni 40	Electrically heated appliances
	Bearing materials	
Tin babbit	Sn 80, Sb 12, Cu 8	High speed bearing bushes
Lead babbit	Pb 85, Sb 10, Sn 5	Railway wagon bearing

Classification of Engineering Materials

Engineering materials can be classified into the following

1. Metals
2. Ceramics
3. Organic materials

Metals are elements atoms of which give up electrons and form metallic bonds. Metals conduct electricity. When two or more metals are melted together they form an alloy.

The property of an alloy is quite different from that of the constituent metals.

Metals may be classified as ferrous metals and non-ferrous metals. Iron and alloys which contain iron are called ferrous metals. Cast iron, wrought iron, carbon steels, alloy steels are examples of ferrous metals.

Metals and alloys which does not contain iron(Fe) are called non ferrous metals. Copper, aluminium, zinc, lead, tin and alloys brass, bronze, duralumin, gunmetal, solder etc and bearing metals (zinc base alloys and nickel base alloys) are examples of non-ferrous metals.

Ceramics

Ceramic materials are products which are made from inorganic materials and have non-metallic properties. Most of them are oxides. Examples are silica, Al_2O_3, MgO, silicon carbide, boron nitride, ferrites etc. Traditional ceramic materials are stone, brick, concrete, clay, glass, vitreous enamel and refractories. Ceramics may be classified as

1. Amorphous ceramics
2. Crystalline ceramics
3. Bonded ceramics
4. Cements

Amorphous ceramics include glasses (soda-glass, Lead glass and borosilicate glass). Glasses are non-crystalline silicates containing oxides such as CaO, Na_2O, K_2O and Al_2O_3.

Glasses are used for electrical insulations, optical lenses and bond metals (hermetic steels).

Crystalline ceramics are used for abrasive and cutting tool materials as they are very hard compared to other materials.

In bonded ceramics individual crystals are bonded together by vitreous matrix. Examples are clay products and refractory materials. Their application is in refractory tiles, furnace linings, electrical insulations, sanitary equipment etc.

Cement is an agglomerated material. It is mainly used for construction works. It is manufactured from clay, limestone, oxides of silicon, aluminium, iron and often magnesium.

Organic Materials

Organic materials are derived directly from carbon. Carbon is chemically combined with hydrogen, oxygen or any other non-metallic substance. Organic materials may be natural or synthetic. Natural organic materials consists of wood, cotton, natural rubber, coal, petroleum, food products etc. Synthetic organic materials consists of synthetic rubber, plastics, lubricants, soap oils, synthetic fibres etc. It is observed that organic materials are made of very large molecules.

Organic compounds consists of molecules formed by carbon atoms along with other non-metal atoms such as hydrogen, nitrogen, oxygen, chlorides etc. Some of the important organic compounds are

1. Saturated organic compounds
2. Unsaturated organic compounds
3. Aromatic organic compounds

Measurement of Hardness

Hardness is generally measured by the intendation made by a harder material. The intendation depends upon the applied load, sharpness of the intended and the time for which applied load is maintained.

Brinell Hardness Test

In brinnel hardness test, a sphere (usually of 10+ 0.01 mm diameter.) made of steel or tungsten carbide is used as the intender. Brinnel Hardness number is given by

$$BHN = \frac{2P}{\pi D\left[D-\sqrt{D^2-d^2}\right]}$$

Where P = Applied load in kg

D = diameter of ball in mm

d = diameter of intendation in mm.

Brinnet Hardness of steel is roughly related to tensile strength of the material. The empirical relationship is given as

Tensile strength (MPa) = 3.55 × BHN

When BHN $\leq$ 175

Tensile strength (MPa) = 3.38 × BHN > 175

Rockwell Test

In the Rockwell test, a spheroconical diamond cone of 120° angle and a spherical apex 0.2 mm radius is used.

Rockwell number (R) =100 – 500 t.

Where t = depth of intendation

Depending upon load a number of scales A, B, C etc are available.

Vicker's and Knoop Hardness Test

In this case a square box pyramid diamond intender having 136° between opposite forces is used.

Vickers Hardness number (VHN)

$$= \frac{1.854L}{D^2}$$

where L = Applied load in Kg

D = measured average diagonal of the intendation in mm.

The Seleroscope work on the principle that rebound height a ball made to fall on the specimen depends on the hardness of the specimen.

Moh's Scale of Hardness

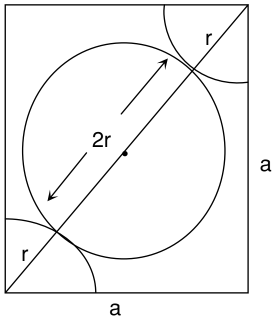
In Moh's scale of hardness different hardness numbers are assigned to ten different minerals of varying hardness. Starting from Talc–1 to diamond–10

Solved Examples

Example 1: Compare lattice parameters of FCC and BCC structure.

Solution: Lattice parameter is the side length of a unit cell: This can be expressed in terms of radius of the atom.

For FCC structure

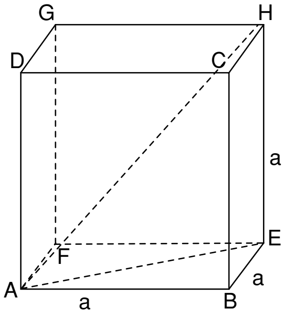


$$a^2 + a^2 = (4r)^2$$

$$2a^2 = 16\, r^2$$

$$a = \frac{4r}{\sqrt{2}}$$

For BCC structure



$$(AH)^2 = (AE)^2 + (HE)^2$$

$$(4r)^2 = 2a^2 + a^2$$

$$= 3a^2$$

$$r = \frac{\sqrt{3}}{4}a$$

$$\text{or } a = \frac{4r}{\sqrt{3}}$$

Example 2: Calculate atomic packing factor for FCC and BCC.

Solution: Atomic Packing Factor

$$APF = \frac{\text{Volume of atoms per unit cell}}{\text{volume of unit cell}}$$

No of atom/unit cell for FCC

$$= \frac{8}{8} + \frac{6}{2} = 4$$

each corner atoms are shared bu 8 unit cells and each face centered atoms are shared by 2 unit cells.

$$\text{APF for FCC} = \frac{4 \times \frac{4}{3}\pi r^3}{9^3}$$

$$= \frac{4 \times \frac{4}{3}\pi r^3}{\left(\frac{4r}{\sqrt{2}}\right)^3}$$

$$= \frac{4^2 \pi}{3 \times 4^3} \times 2\sqrt{2}$$

$$= \frac{\pi\sqrt{2}}{6} = 0.74$$

$$\text{APF for BCC} = \frac{2 \times \frac{4}{3}\pi r^3}{\left(\frac{4r}{\sqrt{3}}\right)^3}$$

$$= \frac{\sqrt{3}}{8}\pi = 0.68.$$

Example 3: Hardness of a steel sample is measured taking Brinnel identation. 10 mm Tungsten carbide ball at 500 Kg f load was used. If the average diameter of identation is 2.5 mm, Brinnel Hardness number is --------

Solution: D = 10 mm
D = 2.5 mm
P = 500 Kgf.

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

$$\frac{2 \times 500}{\pi \times 10\left[10 - \sqrt{10^2 - 2.5^2}\right]}$$

= 100.24.

Example 4: 0.6% Carbon steel was cooled from a temperature of 1500$^{\circ C}$. to room temperature. Discuss the cooling process.

Solution: Steel containing 0.6% carbon is in Liquid +Austenite faustenite. Below 72.3°C, a mixture of ferrite phase at 1500°C. Due to cooling it changes to ferrite and pearlite is obtained.

Example 5: You are given two pieces of steel samples.
(i) 0.2%Carbon steel.
(ii) 0.8% Carbon steel.

Both are heated to austenite region and then quenched in water at room temperature. Describe the changes in each case.

Solution:

(i) 0.2%Carbon steel

If 0.2% Carbon steel is quenched in water from austenite region. We get the martensite consisting of domains of lath of different but limited orientations through a whole domain. This structure is slightly distorted consisting of regions with high densities of dislocation tangles, called lath martensite.

(ii) 0.8% Carbon steel

When 0.8% carbon steel is quenched in water we get mixture of both lath and plate type martensites.

Example 6: Discuss the cooling process of 0.6% carbon steel from 1500$^{\circ C}$ to room temperature.

Solution: During cooling, Liquid + Austenite at 1500°C is converted to complete austenite at 1440$^{\circ C}$. After 750°C it changes into ferrite + austenite which after 723$^{\circ C}$. after 723°C temperature becomes mixture of pearlite and ferrite.

EXERCISES

Practice Problems I

1. A body which is permanently deformed is said to have under gone
   (A) Elastic deformation
   (B) Plastic deformation
   (C) Limit of elastic deformation.
   (D) Uniform deformation

2. Hardness is the property of material due to which it
   (A) Can be drawn into wires
   (B) Will break with little permanent distortion
   (C) Can cut another metal
   (D) Can be rolled or hammered into thin sheets

3. Failure of a material due to fatigue occurs
(A) At elastic limit
(B) Below the elastic limit
(C) At the yield point
(D) Below the yield point.

4. For the materials of tools and machines, the important material property is
(A) Elasticity
(B) Plasticity
(C) Ductility
(D) Malleability

5. No of atoms per unit cell of a face centered cubic (FCC) lattice is
(A) 14
(B) 7
(C) 4
(D) 10

6. Carbon steel containing 0.8% carbon is known as
(A) Eutectic steel
(B) Hypoeutectic steel
(C) Eutectoid steel
(D) Hypereutotoid steel

7. According to IS specification a plain carbon streel designated by 40C8 means that
(A) Carbon content 0.4 percent and Manganese content 0.8 percent.
(B) Carbon content 0.4 percent and Manganese content 0.8 percent.
(C) Carbon content 0.35 to 0.45 percent and Manganese content 0.6 to 0.9 percent.
(D) Carbon content 0.8 percent and Manganese content 0.4 percent.

8. Percentage of carbon content in wrought Iron is about
(A) 0.02
(B) 0.01
(C) 0.2
(D) 0.4

9. Mallealbe Cast Iron is made
(A) By adding magnesium to molten cast iron
(B) By quick cooling of molten cast iron
(C) From white cast iron by annealing process
(D) None of the above

10. When austenite steel is air cooled, the structure produced will be
(A) Martensite
(B) Fine pearlite
(C) Coarse pealite
(D) Troostite

11. In sperodising process, the steel is
(A) Heated above upper critical temperature and cooled in still air
(B) Heated up to lower critical temperature and cooled in still air
(C) Heated slightly above the lower critical temperature and cooled in the furnace.
(D) Heated below lower critical temperature and quenched in water.

12. The process in which steel is heated to a temperature above upper critical temperature and then suddenly cooled by quenching in a salt bath maintained at 250° – 525°C, is called
(A) Normalizing (B) Tempering
(C) Austempering (D) Martempering

13. In the austempering heat treatment process austenite changes to
(A) Martensite (B) Troosite
(C) Sorbite (D) Bainite

14. The heat treatment process for softening hardened steel is
(A) Carburizing (B) Normalizing
(C) Annealing (D) Tempering

15. The hardening process in which carbon and nitrogen are absorbed by the surface of the metal is called
(A) Carburising (B) Nitriding
(C) Cyaniding (D) Flame hardening

16. Delta iron occurs in this temperature range
(A) 1400°C to 1530°C (B) 723 to 910°C
(C) 910 to 1400°C (D) 400 to 723°C

17. An allotropic material has
(A) Different crystal structure at different temperature
(B) Same structure at all temperature
(C) Atoms distributed in random pattern.
(D) More than three types of crystal structures.

18. The most ductile maternal of the following is
(A) FCC (B) BCC
(C) HCP (D) All of the above.

19. "Killed steels" are those steels which
(A) Destroyed by burning
(B) Contains burnt carbon
(C) After their destruction are recycled to produce fresh steel
(D) Are deoxidised in the Laddle with silicon and aluminium.

20. Carbon in Iron is an example of
(A) Interstitial solution
(B) Substitutional solution
(C) Intermetallic compound
(D) All of the above

Practice Problems 2

1. Lattice parameter of metal of FCC lattice having atomic radius. 0.144 nm is
(A) 0.14 nm (B) 0.407 nm
(C) 0.333 nm (D) 0.567 nm

2. Metal with HCP structure is
(A) Silver (B) Iron
(C) Magnesium (D) Aluminium

3. The temperature at which ferromagnetic material becomes paramagnetic is called
(A) Curie temperature
(B) Critical temperature
(C) Inversion temperature
(D) Magnetic temperature

4. The higher packing of atoms structure is
(A) HCP (B) FCC
(C) BCC (D) Simple cubic

5. Basic atoms for HCP space lattice are
(A) 2 (B) 3
(C) 4 (D) 6

6. The percentage of chromium in 18 – 4 – 1 HSS is
(A) 1% (B) 4%
(C) 18% (D) 0.4%

7. Hardest of the following is
(A) Spherodite (B) Martensite
(C) Sorbite (D) Troostite

8. Hardness of steel improves in the process
(A) Annealing (B) Cyniding
(C) Normalising (D) Tempering

9. Choose the most appropriate set of heat treatment process and corresponding process characteristics.
P – Tempering
Q – Austempering
R – Martempering
1. Austenite → Bianite
2. Austenite → Martensite
3. Cementite → Globular structure
4. Hardness and brittleness reduced.
(A) P -4, Q-2, R-1
(B) P-4, Q-3, R-1
(C) P-4, Q-1, R-2
(D) P-2, Q-3, R-4

10. For two specimens A & B of identical size, Young's modulus of specimen A is greater than that of specimen B.
This means
(A) A is stiffer than B
(B) B is stiffer than A
(C) A is harden than B
(D) B is harden than A

11. The material with good ductility is
(A) Mild steel (B) Aluminium
(C) Cast iron (D) Bronze

12. Hardest of the following is
(A) Coarse pearlite (B) Troostite
(C) Bainite (D) Sorbite

13. Carbon percentage in 20 Cr 18 Ni2 steel is
(A) 0.02% (B) 2%
(C) 0.2% (D) Nil

14. Crystal structure of brass is
(A) BCC (B) FCC
(C) HCP (D) Orthorombic

15. Stainless steel contain
(A) Iron, chromium and nickel
(B) Chromium and nickel
(C) Chromium, nickel iron and carbon
(D) Tungsten and Chromium

16. 18-4-1 High speed steel contain
(A) Vanadium 4%, Chromium 18% and tungsten 1%
(B) Vanadium 1% Chromium 4% and tungsten 18%
(C) Vanadium 18%, Chromium 1% and tungsten 4%
(D) none of the above

17. In full annealing, the hypo-euctoid steel is heated from 30°C to 50°C above upper critical temperature and then cooled
(A) In still air
(B) Slowly in the furnace
(C) Suddenly in a cooling medium
(D) Any one other above

18. Which of the following is a case hardening process
(A) Carburizing (B) Cyniding
(C) Nitriding (D) All of these

19. In a material if elastic properties are different in different direction s. The material is
(A) Anisotropic (B) Heterogeneous
(C) Isentropic (D) Isotropic

20. The property of material in which slow extension takes place with time at constant load is known as
(A) Elasticity (B) Creep
(C) Ductility (D) Plasticity

21. For parts subjected to shock and impact loads, the most desirable property is
(A) Elasticity (B) Plasticity
(C) Toughness (D) Malleability

22. The property of a material essential for spring material is
(A) Stiffness (B) Ductility
(C) Resilience (D) Plasticity

23. The property of a material essential for spring material is
(A) Stiffness
(B) Ductility
(C) Malleability
(C) Plasticity

24. Endurance limit is the maximum value of stress a specimen can withstand without failure, for infinite number of cycles where subjected to
(A) Dynamic load
(B) Completely reversed, repeated loads
(C) Static load
(D) Static as well as dynamic load

25. Metal with 60% copper and 40% Zinc is called
(A) Gun metal
(B) Muntz metal
(C) Monel
(D) Admiralty brass

26. Main purpose of spheroidizing treatment is to improve
(A) Hardenability of low carbon steels
(B) Machinability of low carbon steels
(C) Hardenality of high carbon steels
(D) Machinability of high carbon steels

27. During normalizing process of steel, the specimen is heated
(A) Above the upper critical temperature and cooled in still air.
(B) Below the upper critical temperature and cooled in still air
(C) Below the lower critical temperasture and cooled in still air.
(D) Above the upper critical temperature and cooled in the furnace.

28. Percentage of Carbon in grey cast iron is
(A) 0.25 – 0.75
(B) 1.25 – 1.75
(C) 3 – 4
(D) 8 – 10

29. High carbon steels contains carbon percentage of
(A) 0.1 to 0.3
(B) 0.3 to 0.6
(C) 0.6 to 0.8
(D) 0.8 to 1.5

30. Tap, dies and drills contain carbon of the order of
(A) Below 0.5%
(B) Below 1%
(C) Above 1%
(D) Above 2%

PREVIOUS YEARS QEUSTIONS

1. The percentage of carbon in gray cast iron is in range of **[2004]**
(A) 0.25 to 0.75 percent
(B) 1.25 to 1.75 percent
(C) 3 to 4 percent
(D) 8 to 10 percent

2. From the lists given below, choose the most appropriate set of heat treatment process and the corresponding process characteristics: **[2004]**

Process	Characteristics
P. Tempering	1. Austenite is converted into bainite
Q. Austempering	2. Austenite is converted into martensite
R. Martempering	3. Cementite is converted into globular structure
	4. Both hardness and Brittleness are reduced
	5. Carbon is absorbed into the metal

(A) P-3 Q-1 R-5
(B) P-4 Q-3 R-2
(C) P-4 Q-1 R-2
(D) P-1 Q-5 R-4

3. When the temperature of a solid metal increases. **[2005]**
(A) Strength of the metal decreases but ductility increases
(B) Both strength and ductility of the metal decrease
(C) Both strength and ductility of the metal increase
(D) Strength of the metal increases but ductility decreases

4. The main purpose of spheroidising treatment is improve **[2006]**
(A) Hardenability of low carbon steels
(B) Machinability of low carbon steels
(C) Hardenability of high carbon steels
(D) Machinability of high carbon steels

5. Match the items in Columns I and II. **[2006]**

Column I	Column II
(P) Charpy test	**(1)** Fluidity
(Q) Knoop test	**(2)** Microhardness
(R) Spiral test	**(3)** Formability
(S) Cupping test	**(4)** Toughness
	(5) Permeability

(A) P – 4 Q – 5 R – 3 S – 2
(B) P – 3 Q – 5 R – 1 S – 4
(C) P – 2 Q – 4 R – 3 S – 5
(D) P – 4 Q – 2 R – 1 S – 3

6. If a particular Fe-C alloy contains less than 0.83% carbon, it is called **[2007]**
(A) High speed steel
(B) Hypoeutectoid steel
(C) Hypereutectoid steel
(D) Cast iron

7. The effective number of lattice points in the unit cell of simple cubic, body centered cubic, and face centered cubic space lattices, respectively, are **[2009]**
(A) 1, 2, 2
(B) 1, 2, 4
(C) 2, 3, 4
(D) 2, 4, 4

8. The material property which depends only on the basic crystal structure is **[2010]**
(A) Fatigue strength
(B) Work hardening
(C) Fracture strength
(D) Elastic constant

9. The crystal structure of austenite is **[2011]**
(A) Body centered cubic
(B) Face centered cubic
(C) Hexagonal closely packed
(D) Body centered tetragonal

10. During normalizing process of steel, the specimen is heated **[2012]**
(A) Between the upper and lower critical temperature and cooled in still air.
(B) Above the upper critical temperature and cooled in furnace.
(C) Above the upper critical temperature and cooled in furnace.
(D) Between the upper and lower critical temperature and cooled in furnace.

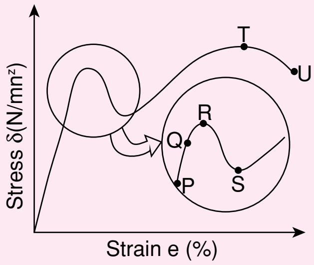
11. For a ductile material, toughness is a measure of **[2013]**
(A) Resistance to scratching
(B) Ability to absorb energy up to fracture
(C) Ability to absorb energy till elastic limit
(D) Resistance to indentation

12. The process of reheating the martensitic steel to reduce its brittleness without any significant loss in its hardness is **[2014]**
(A) Normalising (B) Annealing
(C) Quenching (D) Tempering

13. A metal of initial length L_0 is subjected to drawing process. The length of the rod at any instant is given by the expression, $L(t) = L_0(1 + t^2)$, where t is the time in minutes. The true strain rate (in min $^{-1}$) at the end of one minute is ____ **[2014]**

14. The relationship between true strain (e_T) and engineering strain (e_E) in a uniaxial tension test is given as **[2014]**
(A) $e_E = \text{In}(1+ e_T)$
(B) $e_E = \text{In}(1 - e_T)$
(C) $e_T = \text{In}(1+ e_E)$
(D) $e_T = \text{In}(1 - e_E)$

15. The stress-strain curve for mild steel is shown in the figure given below. Choose the correct option referring to both figure and table. **[2014]**



Point on the Graph	Description of the Point
P	1. Upper Yield Point
Q	2. Ultimate Tensile Strength
R	3. Proportionality Limit
S	4. Elastic Limit
T	5. Lower Yield Point
U	6. Failure

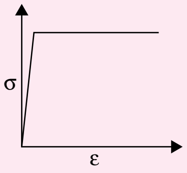
(A) P-1,Q-2,R-3,S-4,T-5,U-6
(B) P-3,Q-1,R-4,S-2,T-6,U-5
(C) P-3,Q-4,R-1,S-5,T-2,U-6
(D) P-4,Q-1,R-5,S-2,T-3,U-6

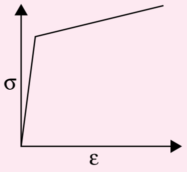
16. Match the heat treatment processes (Group A) and their associated effects on properties (Group B) of medium carbon steel. **[2014]**

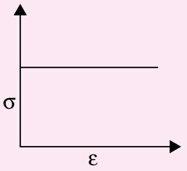
Group A	Group B
P: Tempering	I: Strengthening and grain refinement
Q: Quenching	II: Inducing toughness
R: Annealing	III: Hardening
S: Normalizing	IV: Softening

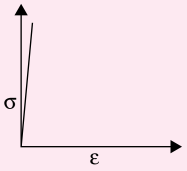
(A) P - III, Q - IV, R - II, S-I
(B) P - II, Q - III, R - IV, S-I
(C) P - III, Q - II, R - IV, S-I
(D) P - II, Q - III, R - I, S-IV

17. Which one of the following types of stress-strain relationship best described the behavior of brittle materials, such as ceramics and thermosetting plastics, (σ = stress and ε = strain)? **[2015]**

(A)


(B)


(C)


(D)


18. The atomic packing factor for a material with body centered cubic structure is ______. **[2015]**

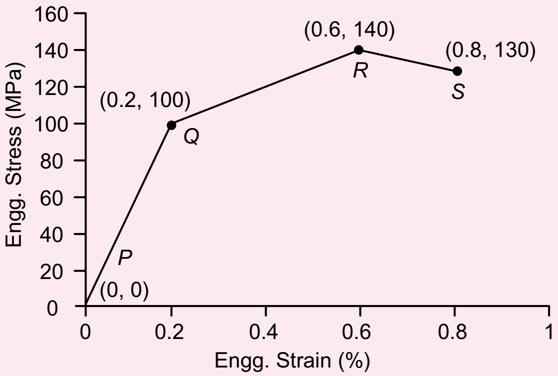
19. The flow stress (in MPa) of a material is given by

$$\sigma = 500 \epsilon^{0.1},$$

where ε is true strain. The Young's modulus of elasticity of the material is 200 GPa. A block of thickness 100 mm made of this material is compressed to 95 mm thickness and then the load is removed. The final dimension of the block (in mm) is ______. **[2015]**

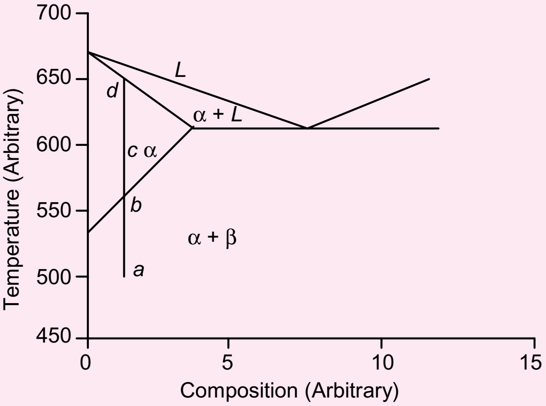
20. The 'Jominy test' is used to find **[2016]**
(A) Young's modulus
(B) hardenability
(C) yield strength
(D) thermal conductivity

21. A hypothetical engineering stress-strain curve shown in the figure has three straight lines *PQ*, *QR*, *RS* with coordinates *P*(0, 0), *Q*(0.2, 100), *R*(0.6, 100), *R*(0.6, 140) and *S*(0.8, 130). '*Q*' is the yield point, '*R*' is the UTS point and '*S*' the fracture point.



The toughness of the material (in MJ/m^3) is ______. **[2016]**

22. In the phase diagram shown in the figure, four samples of the same composition are heated to temperatures marked by *a*, *b*, *c* and *d*.



At which temperature will a sample get solutionized the fastest? **[2016]**

(A) *a*	(B) *b*
(C) *c*	(D) *d*

23. The value of true strain produced in compressing a cylinder to half its original length is: **[2016]**

(A) 0.69	(B) –0.69
(C) 0.5	(D) –0.5

24. In a binary system of *A* and *B*, a liquid of 20% *A* (80% *B*) is coexisting with a solid of 70% *A* (30% *B*). For an overall composition having 40% *A*, the fraction of solid is: **[2016]**

(A) 0.40	(B) 0.50
(C) 0.60	(D) 0.75

25. Engineering strain of a mild steel sample is recorded as 0.100%. The true strain is: **[2016]**

(A) 0.010%	(B) 0.055%
(C) 0.099%	(D) 0.101%

Answer Keys

Exercises

Practice Problems I

1. B **2.** C **3.** D **4.** A **5.** C **6.** C **7.** C **8.** A **9.** C **10.** B
11. C **12.** C **13.** D **14.** D **15.** C **16.** A **17.** A **18.** A **19.** D **20.** A

Practice Problems II

1. B **2.** C **3.** A **4.** B **5.** D **6.** B **7.** B **8.** B **9.** C **10.** A
11. A **12.** C **13.** C **14.** B **15.** C **16.** B **17.** B **18.** D **19.** A **20.** B
21. C **22.** C **23.** A **24.** B **25.** B **26.** D **27.** A **28.** A **29.** D **30.** C

Previous Year's Questions

1. C **2.** C **3.** A **4.** D **5.** D **6.** B **7.** B **8.** D **9.** B **10.** C
11. B **12.** A **13.** 0.9 to 1.1 **14.** C **15.** C **16.** B **17.** D **18.** 0.66 to 0.69
19. 95.14 to 95.20 **20.** B **21.** 0.85 **22.** C **23.** B **24.** A **25.** C