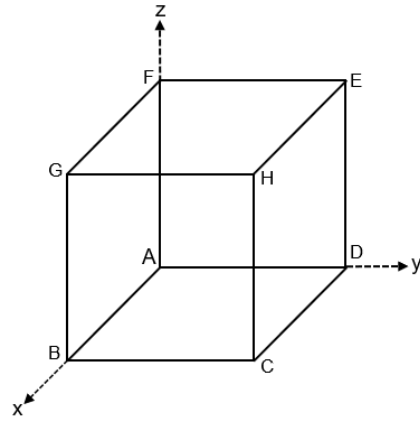1Q. If x, y, and z are three positive axes of the crystallographic coordinate system with origin at point A, then which line points in the direction $[10\bar{1}]$?

A) AD   B) FB   C) DB   D) AG

Solution: B

Moving 1 unit along positive x-axis, 0 units along positive y-axis, 1 unit along negative z-axis points in a direction parallel to line FB.

2Q. The number of members in the family <112> in a cubic crystal are

    A) 8

    B) 12

    C) 24

    D) 48

Solution: C

$[112] = \frac{3!}{2!} = 3\ ways;$ $[\bar{1}12] = 3! = 6\ ways;$ $[11\bar{2}] = \frac{3!}{2!} = 3\ ways;$ $[\bar{1}\bar{1}2] = \frac{3!}{2!} =$ $3\ ways;$ $[\bar{1}1\bar{2}] = 3! = 6\ ways;$ $[\overline{112}] = \frac{3!}{2!} = 3\ ways.$ Total 24.

3Q. The $[100]$ and $[110]$ directions in a cubic crystal are coplanar with

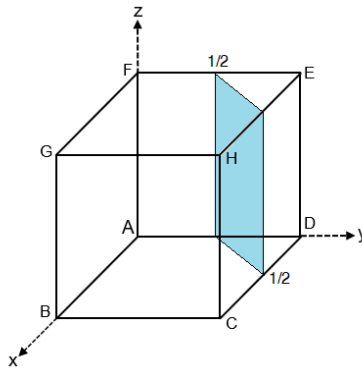   A) [101]

B) [001]

C) [120]

D) [111]

Solution: C

Coplanar means directions lying in the same plane. [100] and [110] directions define x-y plane. Among the options [120] direction lies on x-y plane.

4Q. Determine the Miller indices of the plane shown in the following cubic unit cell:

A) (110)   B) (1-10)   C) (112)   D) (221)

Solution: B

We will move the origin of the coordinate system one-unit cell distance to the right along the y axis; thus, this is a (1-10)plane.

	x	Y	z
Intercepts	a/2	-a/2	∞a
Intercepts in terms of a	1/2	-1/2	∞

Reciprocal of intercepts	2	-2	0
Reduction to smallest integers	1	-1	0
Enclosure	(1-10)		

5Q. The plane with Miller indices (211) is correctly represented in which of the following tetragonal unit cells.

A)

B)

C)
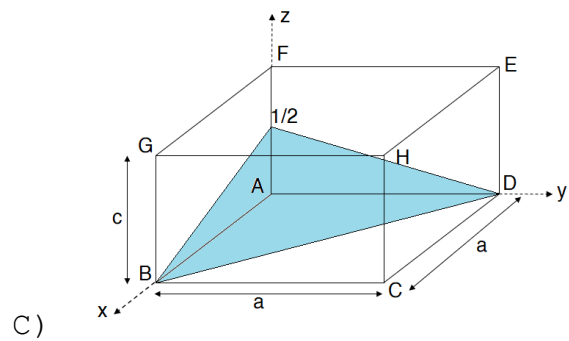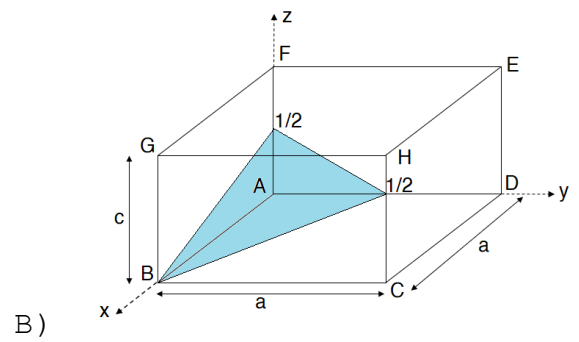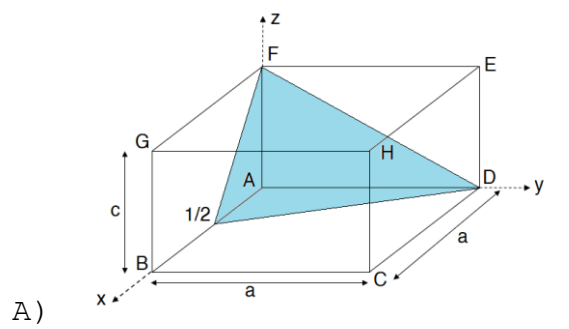
D)
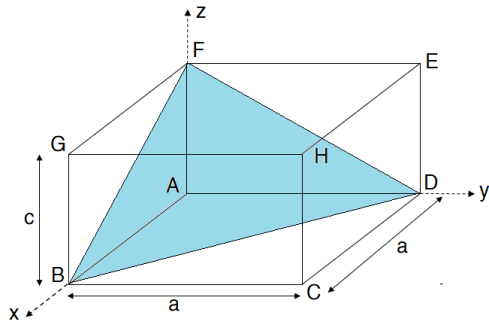
Solution: A

Given Miller indices (211)

	X	y	z
Reciprocal of Miller indices	½	1	1
Intercepts in terms of a and c on coordinate axes	a/2	a	c

6Q. Which one of the following crystal systems is most symmetrical?

    A) Simple cubic

    B) Triclinic

    C) Hexagonal

    D) Tetragonal

Solution: A

Simple cubic have all angles and sides equal. It has a minimum of four 3-fold rotation axes symmetry elements.

7Q. The cubic crystal system is characterized by having

    A) 4 crystallographic axes of unequal length.

    B) No crystallographic axes perpendicular.

    C) 3 crystallographic axes of unequal length.

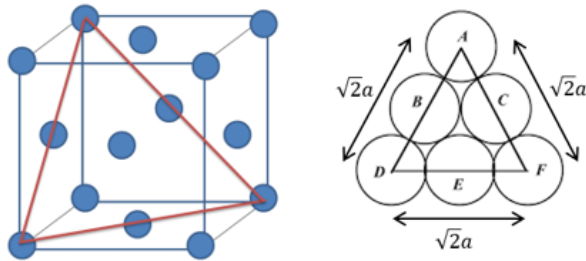   D) 3 crystallographic axes of equal length.

Solution: D

For a cubic crystal system, a = b = c and α=β=γ=90º.

8Q. The atomic density in (111) plane of Ni (FCC) with the lattice parameter of 0.351 nm is.

    A) 2x10^{19} atoms/m^2

    B) 3.45x10^{19} atoms/m^2

    C) 2.53x10^{19} atoms/m^2

    D) 1.87x10^{19} atoms/m^2

Solution: D

(111) plane in FCC crystal is shown in the following figure.

$$Planar\ Density = \frac{No.\,of\ atoms\ centered\ on\ a\ plane}{area\ of\ plane}$$

1/6th portion of atoms A, D, F and 1/2 portion of atoms B, C, E are inside the triangle. Therefore total no. of atoms centered on the (111) plane is 3/6 + 3/2 = 2 atoms.
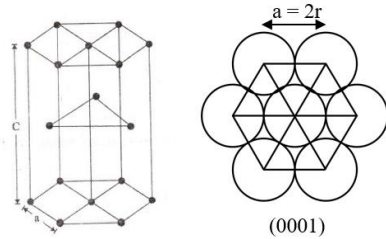
$$Area\ of\ plane = \frac{\sqrt{3}}{4(\llbracket\sqrt{2}a\rrbracket)^2} = \frac{\sqrt{3}}{2}a^2$$

$$Planar\ Density = \frac{2}{\frac{\sqrt{3}}{2}a^2} = \frac{4}{\sqrt{3}(3.51^2 \times 10^{-20})} = 1.87 \times 10^{19} \frac{atoms}{m^2}$$

9Q. The planar density of (0001) plane of Ti (HCP) with lattice parameters a = 0.295 nm and c = 0.468 nm is:

A) 5.27×10^{18} atoms/m^2

B) 5.27×10^{19} atoms/m^2

C) 1.32×10^{19} atoms/m^2

D) 1.32×10^{18} atoms/m^2

Solution: C

(0001)

1/3rd part of each of 6 perimeter atoms are centered on (0001) plane and 1 full center atom is centered on this plane; this gives rise to 3 equivalent atoms belonging to this plane.

In terms of lattice parameter 'a' the area of each of the 6 equilateral triangle is $\frac{\sqrt{3}a^2}{4}$. The total area of the plane is $\frac{6\sqrt{3}a^2}{4}$.

$$Planar\ Density = \frac{No.\,of\ atoms\ centered\ on\ the\ plane}{area\ of\ plane} = \frac{3}{\frac{6\sqrt{3}a^2}{4}} = \frac{2 \times 10^{18}}{\sqrt{3} \times 0.295^2}$$

$$= 1.32 \times 10^{19} \frac{atoms}{m^2}$$

10Q. Which plane and direction of BCC unit cell has highest planar density and highest linear density?

A) (111) and [111]

B) (110) and [111]

C) (100) and [110]

D) (110) and [100]

Solution: B
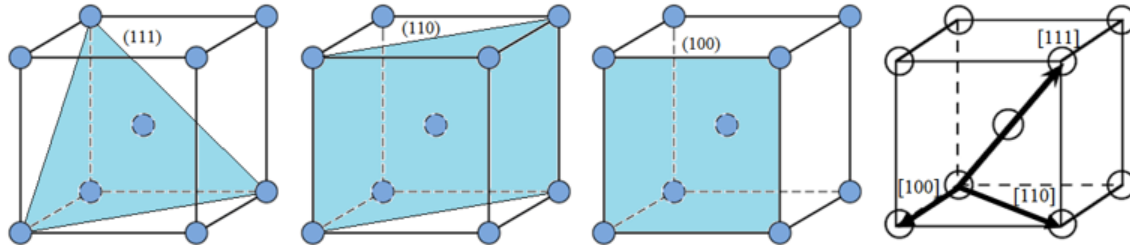
$$PD_{(111)} = \frac{\frac{1}{2}}{\frac{\sqrt{3}}{4}(\sqrt{2}a)^2} = \frac{1}{\sqrt{3}a^2} = \frac{0.57}{a^2}$$

$$PD_{(110)} = \frac{2}{\sqrt{2}a^2} = \frac{\sqrt{2}}{a^2} = \frac{1.41}{a^2}$$

$$PD_{(100)} = \frac{1}{a^2} = \frac{1}{a^2}$$

$$LD_{[111]} = \frac{2}{\sqrt{3}a} = \frac{1.15}{a}$$

$$LD_{[110]} = \frac{1}{\sqrt{2}a} = \frac{0.7}{a}$$

$$LD_{[100]} = \frac{1}{a} = \frac{1}{a}$$
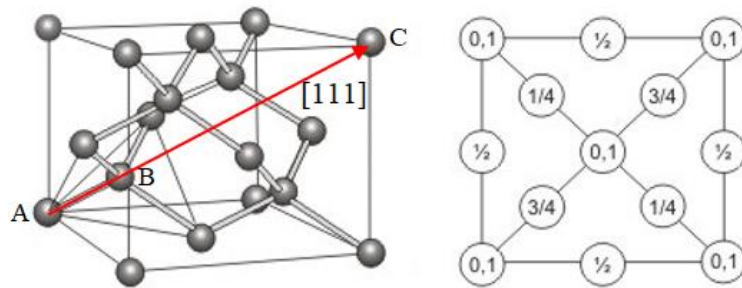
Thus, (110) plane and [111] direction have highest planar and linear densities respectively in BCC unit cell.

11Q. The atomic packing fraction for DC structure is
    A) 0.68
    B) 0.74
    C) 0.34
    D) 0.52

Solution: C

Atoms A and B are in contact with each other along [111] direction. The atomic radius is thus half the distance between the centers of atoms A and B.

Distance between atoms A (0,0,0) and B (a/4, a/4, a/4) is $\frac{\sqrt{3}a}{4}$. Thus, radius $R=\frac{\sqrt{3}a}{8}$. Number of atoms associated with each unit cell (n) = 1/8 (8) + 1/2 (6) + 4 = 8

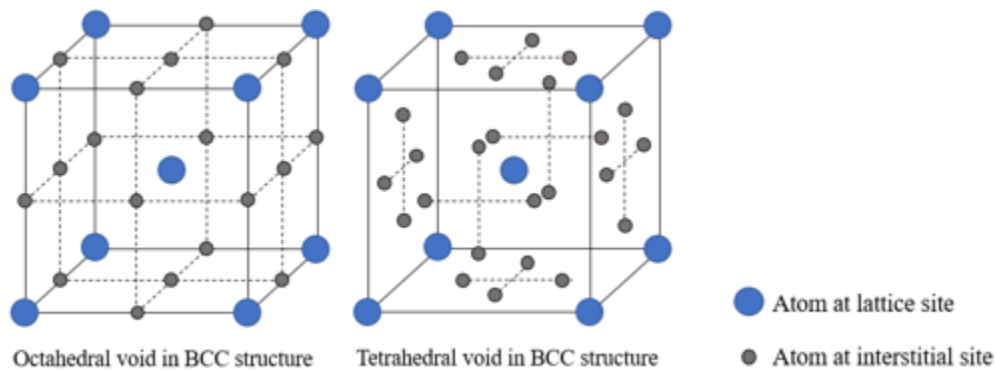APF = n x volume of 1 atom / volume of unit cell

$$APF = \frac{8 \times \frac{4}{3}\pi R^3}{a^3} = \frac{8 \times 4\pi \times \left(\frac{\sqrt{3}a}{8}\right)^3}{3 \times a^3} = 0.34$$

12Q. The number of octahedral voids and tetrahedral voids per atom in BCC structure is

    A) 6 and 3

    B) 4 and 8

    C) 3 and 6

Solution: C

Octahedral void in BCC structure   Tetrahedral void in BCC structure

● Atom at lattice site

● Atom at interstitial site

Number of octahedral voids per unit cell = 12 x (1/4) + 6 x (1/2) = 6

Number of octahedral voids per atom = 6/2 = 3

Number of tetrahedral voids per unit cell = 24 x (1/2) = 12

Number of tetrahedral voids per atom = 12/2 = 6

13Q. Carbon atoms in α-iron are present in which of the following positions and why?

A) Tetrahedral – largest site in BCC unit cell

B) Tetrahedral – causes less distortion of BCC unit cell compared to when carbon is present in octahedral site

C) Octahedral – largest site in BCC unit cell

D) Octahedral – causes less distortion of BCC unit cell

compared to when carbon is present in tetrahedral site

Solution: D

Carbon atoms in α-iron are present in octahedral void, though it is smaller of the two. A carbon atom in the tetrahedral void, if present would displace all the four atoms of the iron at four corners of the tetrahedron causing more distortion, whereas if present in octahedral void displaces only two nearest atoms resulting in less distortion. This makes the interstitial solubility of carbon in α-iron more difficult than its solubility in γ-iron because of severe distortion which takes place (due to smaller size of the octahedral void) in α-iron. This explains why, at the same temperature of 727°C, γ-iron can dissolve carbon up to 0.77 wt. %, whereas α-iron is able to dissolve up to 0.025 wt. %.

14Q. Nitrogen diffuses in Fe by which one of the following mechanisms?

    A) Vacancy
    B) Interstitial
    C) Ring
    D) Interstitialcy

Solution: B

Vacancy Mechanism: The diffusion is said to take place by the vacancy mechanism if an atom on a normal site jumps into an adjacent unoccupied lattice site (vacancy).

Interstitial Mechanism: If an atom on an interstitial site moves to one of the neighboring interstitial sites, the diffusion occurs by an interstitial mechanism. Diffusion of interstitially dissolved light atoms, e.g. H, C, N, and O in metals provides the best-known examples of this mechanism.

Interstitialcy Mechanism: If the distortion becomes too large to make the interstitial mechanism probable, interstitial atoms may move by another type of mechanism. In the interstitialcy mechanism an interstitial atom pushes one of its nearest neighbors on a normal lattice site into another interstitial position and itself occupies the lattice site of the displaced atom.

Ring Mechanism: In this mechanism a group of atoms moves around in a circular fashion, each atom in the group taking the place of its neighbor in the direction of motion.

15Q. Among the following methods, which method is used for measuring diffusion coefficient in self-diffusion.

    A) Mass spectrometry

    B) Radio-active tracer technique

    C) Spectrophotometry

    D) Computed Tomography analysis

Solution: B
Self-diffusion involves the motion of atoms that are all of the same type; therefore, it is not subject to observation by compositional changes, as with inter-diffusion. Self-diffusion may be monitored by using radioactive isotopes of the metal being studied. The motion of these isotopic atoms may be monitored by measurement of radioactivity level using Radio-active tracer technique.

16Q. Using the data given in the following table arrange the

solute metals in descending order of their extensive substitutional solid solubility in solvent copper.

Element	Atomic Radius (nm)	Crystal Structure	Electronegativity
Cu	0.128	FCC	1.9
Zn	0.131	HCP	1.6
Ni	0.125	FCC	1.8
Ag	0.144	FCC	1.7

    A) Zn > Ag > Ni

    B) Ni > Zn > Ag

    C) Ni > Ag > Zn

    D) Ag > Ni> Zn

Solution: B

% difference in atomic radius by formula,

$$\% \, difference = \frac{r_x - r_{Cu}}{r_{Cu}} \times 100$$

$$Cu - Zn \,\% \, difference = \frac{0.131 - 0.128}{0.128} \times 100 = 2.3\%$$

$$Cu - Ni \,\% \, difference = \frac{0.125 - 0.128}{0.128} \times 100 = -2.3\%$$

$$Cu - Ag \,\% \, difference = \frac{0.144 - 0.128}{0.128} \times 100 = 12.5\%$$

Electronegativity Difference,

Cu-Zn: 1.9-1.6 = 0.3

Cu-Ni: 1.9-1.8 = 0.1

Cu-Ag: 1.9-1.7 = 0.2

Ni has highest solubility as it has just 2.3% difference in atomic radius, has lowest electronegativity difference and has same crystal structure as Cu.

Zn solubility is next to Ni as, though it has just 2.3% difference in atomic radius its electronegativity difference is more compared to Ni and its crystal structure is not similar to that of Cu.

Ag has least solubility among all three solute atoms because of large difference in atomic radius though it has similar crystal structure.

Observed solubility: Ni in Cu = 100%; Zn in Cu = 38% at 456°C; Ag in Cu = 8% at 780°C

17Q.Calculate the electron-to-atom ratio in a copper-base alloy containing 20% zinc, 3% aluminium and 3% silicon. Assuming the maximum solubility corresponds to e/a of 1.38, would this alloy be a single solid solution? Given atomic weights of Cu, Zn, Al and Si are 63.5, 65.4, 27 and 28 g/mol

respectively.

A) 1.5 and would have single solid solution

B) 1.2 and would not have single solid solution

C) 1.5 and would not have single solid solution

D) 1.2 and would have single solid solution

Solution: A

Solid solubility is affected by the relative valence of the elements. The ratio of number of valence electrons per atom, e/a, affects the solubility. Solutes that raise the e/a, generally have a higher solubility than those that lower the e/a.

The maximum solubility of many elements in copper base alloys corresponds to an e/a ratio of 1.35-1.4.

Hume Rothery discovered that regardless of the alloying element used, the phase change occurs at a fixed value of the e/a ratio.

Copper (FCC) being monovalent has as pure copper, the electron atom ratio one. When zinc is added, then at 50 atom percent zinc, beta phase (BCC) appears; e/a = 1.5. A complex cubic γ-phase appears at a ratio of 1.62 and a close packed hexagonal ε-phase appears at 1.75.

These compounds which occur as a result of the valence electron to atom ratio, are called "electron compounds" or "Hume Rothery phases".

Assume 100g of sample. 74g of Cu contribute (1 e/a) (74g/63.5 g/mol) = 1.165 mol of e. Zn contributes (2 e/a) (20g/65.4 g/mol) = 0.612 mol of e. Al contributes (3 e/a) (3g/27 g/mol) = 0.333 mol of e. Si contributes (4 e/a) (3g/28 g/mol) = 0.428 mol of e. The total is 1.165 + 0.612 + 0.333 + 0.428 = 2.538 mol of e. The total number of atoms is 74/63.5 + 20/65.4 + 3/27 + 3/28 = 1.689 mol of atoms. The e/a = 2.538/1.689 = 1.5. This would predict that the alloy would be single BCC solid solution.

18Q. Find the entropy of mixing of 0.3 mole of Ag atoms, 0.5 mole of Cu atoms and 0.2 mole of Au atoms on 1 mole of sites in J/mol-K and choose the correct reason why a solid solution can form or not form.

A) ΔS = -8.56. Entropy is negative hence a solid solution is not formed.

B) ΔS = -8.56. Entropy is negative hence a solid solution is

formed.

C) ΔS = 8.56. Entropy is positive hence a solid solution is formed.

D) ΔS = 8.56. Entropy is positive hence a solid solution is not formed.

Solution: C

Entropy of mixing is given by the equation,

$$\Delta S = -R(X_A ln(X_A) + X_B ln(X_B) + X_C ln(X_C))$$

$$\Delta S = -8.314 \frac{J}{mol-K} (0.3ln(0.3) + 0.5ln(0.5) + 0.2ln(0.2)) = 8.56 \frac{J}{mol-K}$$

19Q. Electro-chemical compounds are formed between two elements when

A) there is large electronegativity difference

B) there is more than 15% difference in atomic radius

C) the crystal structures are different

D) when electron/atom ratio is far less than maximum solubility e/a ratio

Solution: A

Electro-chemical compounds are formed between more electropositive and more electronegative elements.

20Q. The phases that are present and the phase compositions for the alloy just below eutectic point in a Pb-Sn phase diagram is

Composition (at% Sn)
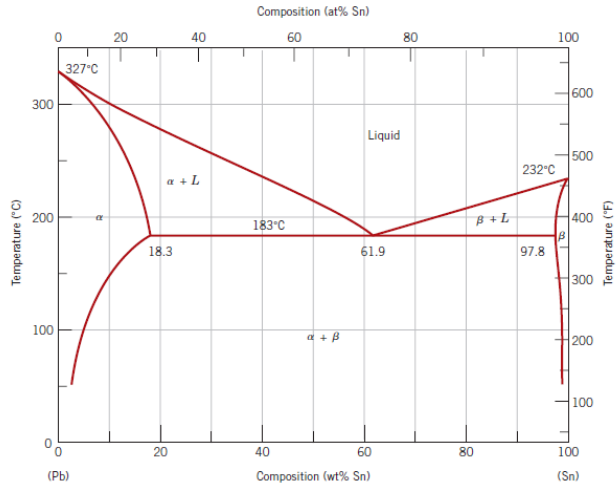
A) αand βphases with C$_\alpha$= 18.3% Sn & 81.7% Pb and C$_\beta$= 97.8% Sn & 2.2% Pb.

B) α, β and Lphases with C$_\alpha$= 18.3% Sn & 81.7% Pb; C$_\beta$= 97.8% Sn & 2.2% Pb and L = 61.9% Sn & 38.1% Pb.

C) α and β phases with C$_\alpha$= 61.9% Sn & 38.1% Pb and C$_\beta$= 38.1% Sn & 61.9% Pb.

D) α and β phases with C$_\alpha$= 97.8% Sn & 18.3% Pb and C$_\beta$= 97.8% Sn & 18.3% Pb.

Solution: A

18.3% Sn & 81.7% Pb
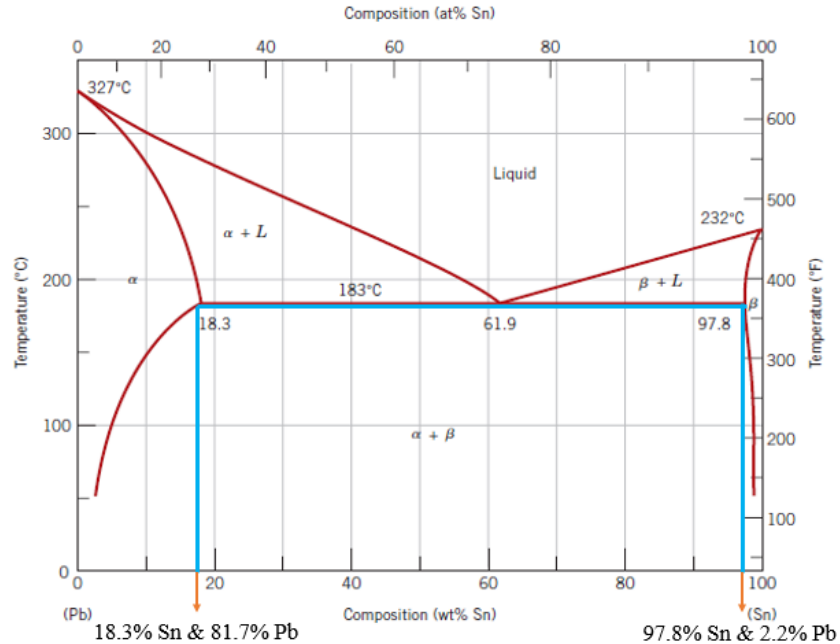
97.8% Sn & 2.2% Pb

The phases that are present are αand βphases with Cα= 18.3% Sn & 81.7% Pb and Cβ= 97.8% Sn & 2.2% Pb.

21Q. For alloys of two hypothetical metals A and B, there exist an α, A-rich phase and a β, B-rich phase. From the mass fractions of both phases for two different alloys provided in the table below, (which are at the same temperature), determine the composition of the phase boundary (or solubility limit) for both.

Alloy Composition	Fraction α-phase	Fraction β-phase
70 wt.% A-30 wt.% B	0.78	0.22
35 wt.% A-65 wt.% B	0.36	0.64

A) Cα= 53.7 wt.% A-46.3 wt.% B and Cβ = 25 wt.% A-75 wt.% B

B) Cα= 88.3 wt.% A-11.7 wt.% B and Cβ = 5 wt.% A-95 wt.% B

C) Cα= 75.5wt.% A-24.5 wt.% B and Cβ = 15 wt.% A-85 wt.% B

D) Cα= 63.3 wt.% A-36.7 wt.% B and Cβ = 7.7 wt.% A-92.3 wt.% B

Solution: B

We have to solve for compositions at the phase boundaries for both α and β phases (i.e., C_α and C_β). We may set up two independent lever rule expressions, one for each composition, in terms of C_α and C_β as follows:

$$W_{\alpha 1} = 0.78 = \frac{C_\beta - C_{01}}{C_\beta - C_\alpha} = \frac{C_\beta - 70}{C_\beta - C_\alpha}$$

$$W_{\alpha 2} = 0.36 = \frac{C_\beta - C_{02}}{C_\beta - C_\alpha} = \frac{C_\beta - 35}{C_\beta - C_\alpha}$$

In these expressions, compositions are given in wt.% of A. Solving for C_α and C_β from these equations, yield

$C_\alpha = 88.3$ (or 88.3 wt% A-11.7 wt% B)

$C_\beta = 5.0$ (or 5.0 wt% A-95.0 wt% B)

22Q. A hypothetical A-B alloy of composition 40 wt.% B-60 wt.% A at some temperature is found to consist of mass fractions of 0.66 and 0.34 for the α and β phases, respectively. If the composition of the α phase is 13 wt.% B-87 wt.% A, what is the composition of the β phase?

    A) C_β = 92.4 wt.% B-7.6 wt.% A

    B) C_β = 87.5 wt.% B-12.5 wt.% A

    C) C_β = 75 wt.% B-25 wt.% A

    D) C_β = 83.3 wt.% B-16.7 wt.% A

Solution:A

Given,

C_0 = 40 wt.% B-60 wt.% A

C_α = 13 wt.% B-87 wt.% A

W_α = 0.66

W_β = 0.34

$$W_\alpha = 0.66 = \frac{C_\beta - C_0}{C_\beta - C_\alpha} = \frac{C_\beta - 40}{C_\beta - 13}$$

C_β = 92.4 wt.% B-7.6 wt.% A

23Q. Consider a binary system of A and B with melting point of pure A = 1769°C and melting point of pure B = 961°C. At 1185°C, the α solid solution (containing 20% of B), the β solid solution (containing 60% of B) and liquid (containing 80% of B) are in three-phase equilibrium. At room temperature, the maximum solubility of B in the α phase is 10% and the maximum solubility of A in the β phase is 35%. Determine the type of reaction that is taking place at 1185°C and the weight fractions of the phases present in the material of overall composition of 75% B at 1186°C.

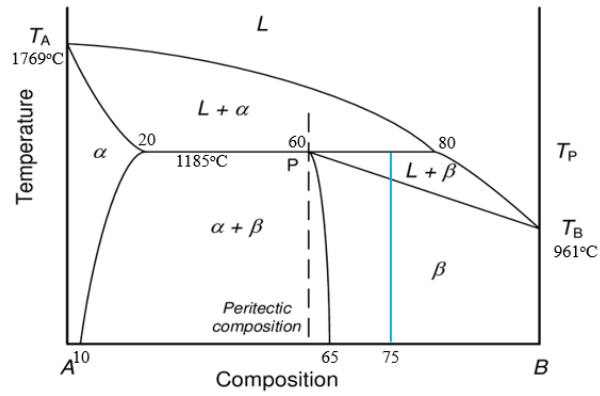A) Monotectic reaction and f_α = 0.67; f_1 = 0.33

B) Eutectic reaction and f_1 = 0.33; f_β = 0.67

C) Peritectic reaction and f_1 = 0.92; f_α = 0.08

D) Eutectoid reaction and f_α = 0.27; f_β = 0.73

Solution: C

The peritectic phase diagram for the question, looks similar to the one shown below

At 1186°C only liquid and α phases are present.

$$f_l = \frac{75 - C_\alpha}{C_l - C_\alpha} = \frac{75 - 20}{80 - 20} = 0.92$$

$$f_\alpha = \frac{C_l - 75}{C_l - C_\alpha} = \frac{80 - 75}{80 - 20} = 0.08$$

24Q. A 2.0 kg specimen of an 85 wt.% Pb-15 wt.% Sn alloy is heated to 200°C; at this temperature it is entirely an α-phase solid solution. The alloy is to be melted to the extent that 50% of the specimen is liquid, the remainder being the α-phase. This may be accomplished by changing its composition while holding the temperature constant. How much tin must be added to the 2.0-kg specimen at 200°C to achieve this state?
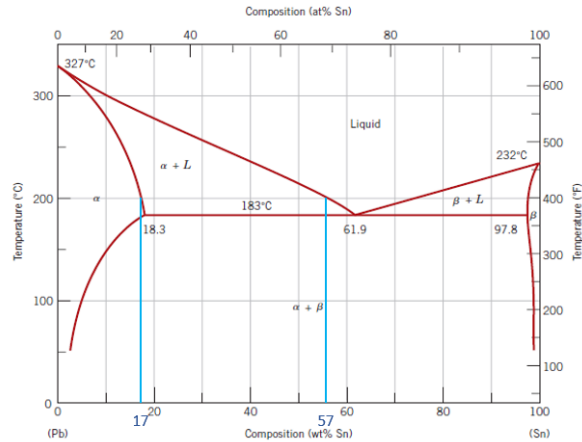
A) 0.456 kg   B) 0.698 kg   C) 1.000 kg   D) 0.956 kg

Solution: B

At 200°C and within α + L phase region

$C_\alpha = 17$ wt% Sn-83 wt% Pb

$C_L = 57$ wt% Sn-43 wt% Pb

Let C_0 be the new alloy composition to give $W_\alpha = W_l = 0.5$

$$W_\alpha = 0.5 = \frac{C_L - C_0}{C_L - C_\alpha} = \frac{57 - C_0}{57 - 17}$$

Solving for C_0 we get $C_0 = 37$ wt.% Sn.

Now, let M_{Sn} be the mass of Sn added to the alloy to achieve this new composition. The amount of Sn in the original alloy is

(0.15) x (2 kg) = 3 kg

Now,

$$\left| \frac{0.30 \text{ kg} + m_{Sn}}{2.0 \text{ kg} + m_{Sn}} \right| \times 100 = 37$$

Solving for M_{Sn} we get $M_{Sn} = 0.698$ kg

25Q. An unknown microstructure consists of very fine and parallel needle-shaped particles of cementite that are

surrounded by an α-ferrite matrix. The microstructure is of

    A) Pearlite

   B) Bainite

    C) Spheroidite

    D) Austenite

Solution: B

26Q. In the eutectoid steel, which one of the following structures does not form during continuous cooling?

    A) Fully pearlite

    B) Martensite

    C) Pearlite + Bainite

    D) Fully Bainite

Solution: D

Fully bainitic structure is not possible during continuous cooling. 100% bainitic structure can be formed only by cooling rapidly enough to miss the nose of the curve and then holding in the temperature range at which bainite is formed.

100% Bainite
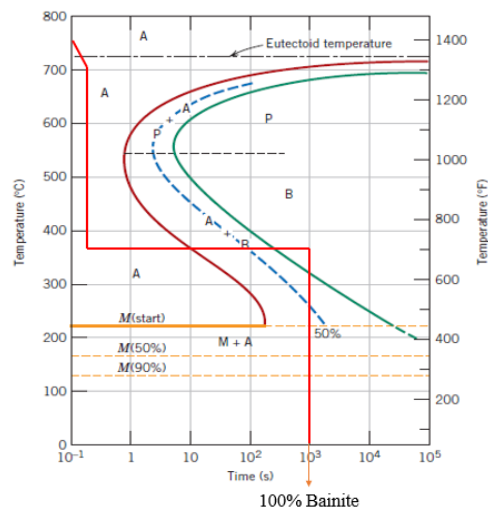
27Q. Rank the following iron – carbon alloys and associated microstructures from the hardest to the softest

P) 0.25 wt.% C with coarse pearlite, Q) 0.80 wt. % C with spheroidite. R) 0.25 wt. % C with spheroidite, S) 0.80 wt. % C with fine pearlite.

   A) P > Q > R > S
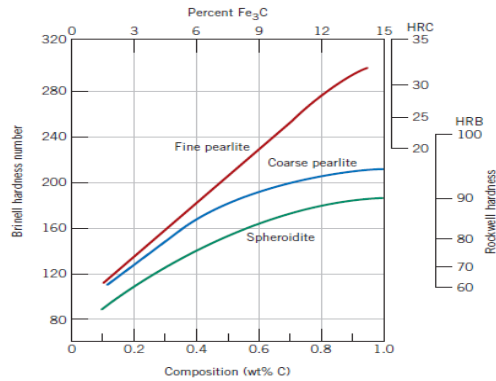
   B) S > Q > P > R

   C) Q > S > R > P

   D) S > P > Q > R

Solution: B

Cementite is much harder but more brittle than ferrite. Thus, increasing the fraction of Fe_3C in a steel while holding other microstructural elements constant will result in a harder and stronger material.

The layer thickness of each ferrite and cementite phases in the microstructure also influences the mechanical behavior of the material. Fine pearlite is much harder and stronger than coarse pearlite.

The cementite phase has distinctly different shapes and arrangements in the pearlite and spheroidite microstructures. Alloys containing pearlitic microstructures have greater strength and hardness than do those with spheroidite. Alloys having spheroidite microstructure with higher percentages of carbon has higher hardness.

Percent Fe₃C graph — Brinell hardness number vs Composition (wt% C), showing Fine pearlite, Coarse pearlite, and Spheroidite curves, with HRC, HRB and Rockwell hardness scales.

28Q. The microstructure of tempered martensite consists of

A) elongated particles of Fe_3C phase in ferrite matrix.

B) sphere like particles of Fe_3C phase embedded in continuous α – phase matrix.

C) extremely small and uniformly dispersed cementite particles embedded within a continuous ferrite matrix.

D) needle shaped martensitic phase in retained austenite phase.

Solution: C

29Q. Describe the simplest heat treatment procedure that would be used in converting a 0.76 wt.% C steel from bainite to pearlite.

A) heating the sample to austenitic temperature, quenching in water and finally tempering at 250°C

B) heating the sample to austenitic temperature and quenching in iced brine

C) heating the sample to austenitic temperature, quenching in a lead bath at 500°C and then cooling it to room temperature

D) heating the sample to austenitic temperature followed by isothermal holding between eutectoid temperature and the nose

Solution: D
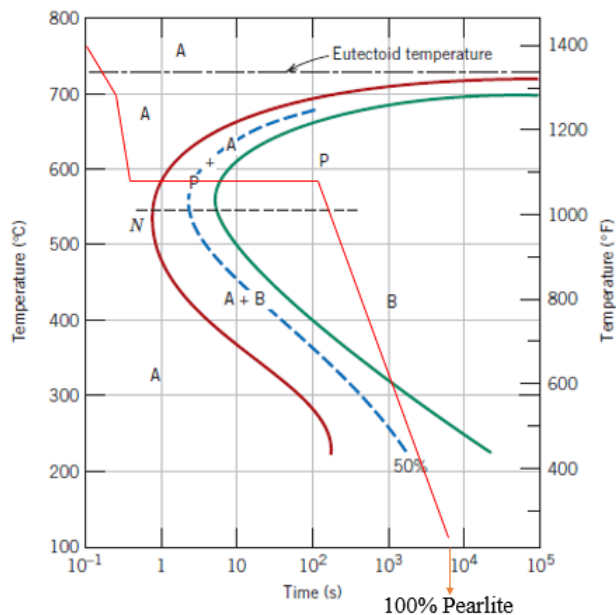
30Q. Arrange the following in terms of increasing severity of quench

P. Oil quenching

Q. Water quenching

R. Water quenching with agitation

S. Brine quenching

    A) P < Q < R < S

B) Q < R < P < S

C) P < Q < S < R

D) Q < P < R < S

Solution: C

The cooling power of water is in between brine and oils. Spray quenching or water quenching with agitation provides more cooling rate than still brine.

High specific heat and high latent heat of vaporization of water are responsible for high cooling power of water compared with oils.

The cooling rate of water is less than brine because of easy formation of vapor – blanket with water as quenchant. In brine, the heating of the solution at the steel surface causes the deposition of the salt on hot steel surface. This layer of solid crystals disrupts with mild explosive violence, and throws off a cloud of crystals. This action destroys the vapor – film from the surface, and thus, permits direct contact of the coolant with the steel surface with an accompanying rapid removal of heat.