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Code: AE04 **Subject: MATERIALS AND PROCE[...]**
PART - I

TYPICAL QUESTIONS & ANSWERS

OBJECTIVE TYPE QUESTIONS

Each Question carries 2 marks.

Choose correct or the best alternative in the following:

Q.1 The correct order of the coordination number is SC, BCC, FCC and HCP unit cells is

(A) 12, 8, 12, 6. **(B)** 6, 8, 12, 12.
(C) 8, 6, 12, 12. **(D)** 6, 12, 12, 8.

Ans: B

Q.2 Frankel and Schottky imperfections are

(A) dislocations in ionic crystals.
(B) Grain boundaries in covalent crystals.
(C) Vacancies in ionic crystals.
(D) Vacancies in covalent crystals.

Ans: C

Q.3 The electronic polarizability α_e of a mono atomic gas atom where R is the radius of circular orbit is

(A) $4\pi\epsilon_0$ **(B)** $4\pi\epsilon_0 R$
(C) $4\pi\epsilon_0 R^3$ **(D)** $4\pi\epsilon_0 R^2$

Ans: C

Q.4 The forbidden energy gap of carbon in diamond structure is

(A) 7.0 ev **(B)** 1.0 ev
(C) 0.01 ev **(D)** none

Ans: A

Q.5 For silicon doped with trivalent impurity,

(A) $n_e >> n_h$ **(B)** $n_e > n_h$.
(C) $n_h >> n_e$. **(D)** $n_h > n_e$.

Ans: C

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Q.6 With increase in temperature, the orientation polarization in general
(A) decreases. **(B)** increases.
(C) remains same. **(D)** none of these.

Ans: A

Q.7 A suitable material for audio and TV transformers is
(A) Fe – 4% Si. **(B)** Ferrite.
(C) Fe – 30% Ni. **(D)** Pure Fe.

Ans: B

Q.8 Which of the following is not the function of oxide layer during IC fabrication
(A) to increase the melting point of silicon.
(B) to mask against diffusion or ion implant.
(C) to insulate the surface electrically.
(D) to produce a chemically stable surface.

Ans: A

Q.9 In normalizing, one of the following is not correct:
(A) it relieves internal stresses **(B)** it produces a uniform structure.
(C) the rate of cooling is rapid **(D)** the rate of cooling is slow.

Ans: D

Q.10 Which of the following materials is used for making permanent magnet.
(A) Platinum cobalt **(B)** Alnico
(C) Carbon Steel **(D)** all the three

Ans: D

Q.11 The number of atoms present in the unit cell of HCP structure is
(A) 2. **(B)** 4.
(C) 6. **(D)** 7.

Ans: C

Q.12 Metallic bond is not characterized by
(A) ductility. **(B)** high conductivity.
(C) directionality. **(D)** opacity.

Ans: C

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Q.13 The Einstein relationship between the diffusion constant D_n and mobility. μ_n for electron is

(A) $\frac{D_n}{\mu_n} = \frac{2K_BT}{e}$.

(B) $\frac{D_n}{\mu_n} = \frac{e}{K_BT}$.

(C) $\frac{D_n}{\mu_n} = \frac{K_BT}{e}$.

(D) $\frac{D_n}{\mu_n} = K_BT - E$.

Where T is the temperature and K_B is Boltzmann's constant.

Ans: C

Q.14 If the Fermi energy of silver at 0^0 K is 5 electron volt, the mean energy of electron in silver at 0^0 K is

(A) 6 electron volt.

(B) 12 electron volt.

(C) 1.5 electron volt.

(D) 3 electron volt.

Ans: D

Q.15 The Fermi level in an n-type semiconductor at 0^0 K lies

(A) below the donor level.

(B) Half way between the bottom of conduction band and donor level.

(C) Exactly in the middle of hand gap.

(D) Half way between the top of valence band and the acceptor level.

Ans: B

Q.16 Hard magnetic material is characterized by

(A) High coercive force and low residual magnetic induction..

(B) Low coercive force and high residual magnetic induction..

(C) Only low coercive force.

(D) High coercive force and high residual magnetic induction..

Ans: D

Q.17 Piezoelectric effect is the production of electricity by

(A) chemical effect.

(B) pressure.

(C) varying field.

(D) temperature.

Ans: B

Q.18 Electromigration in metallization refers to the diffusion (under the influence of current) of

(A) Al.

(B) Cu in A1-Cu alloy.

(C) Si.

(D) Na.

Ans: A

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Q.19 Fine grain sizes are obtained by

(A) slow cooling. **(B)** increasing nucleation rate.
(C) decreasing growth rate **(D)** fast cooling.

Ans: A

Q.20 Zinc has hcp structure. In a unit cell of zinc, the zinc atoms occupy

(A) 74% of volume of unit cell. **(B)** 80% of volume of unit cell.
(C) 68% of volume of unit cell. **(D)** 90% of volume of unit cell.

Ans: A

Q.21 The density of carriers in a pure semiconductor is proportional to

(A) $\exp(-E_g/kT)$ **(B)** $\exp(-2E_g/kT)$
(C) $\exp(-E_g/kT^2)$ **(D)** $\exp(-E_g/2kT)$

Ans: A

Q.22 The probability of occupation of an energy level E, when $E - E_F = kT$, is given by

(A) 0.73 **(B)** 0.63
(C) 0.5 **(D)** 0.27

Ans: D

Q.23 The majority charge carriers in p-type semiconductor are

(A) ions. **(B)** holes.
(C) free electrons. **(D)** conduction electrons.

Ans: B

Q.24 Polarization in a dielectric on application of electric field is

(A) Displacement/separation of opposite charge centres.
(B) Passing of current through dielectric.
(C) Breaking of insulation.
(D) Excitation of electrons to higher energy level.

Ans: A

Q.25 Which one of the following is not the purpose of full annealing

(A) refines grains **(B)** induces softness.
(C) removes strains and stresses **(D)** produces hardest material.

Ans: D

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Q.26 Which of the following elements is a covalently bonded crystal?
(A) aluminium **(B)** sodium chloride
(C) germanium **(D)** lead

Ans: C

Q.27 The radius of first Bohr orbit in the hydrogen atom is about
(A) 0.053 Å **(B)** 0.530 Å
(C) 5.31 Å **(D)** 53.10 Å

Ans: B

Q.28 Binary phase diagrams of two component systems are usually
(A) two dimensional plots of temperature and pressure.
(B) two dimensional plots of temperature and composition.
(C) two dimensional plots of pressure and composition.
(D) two dimensional plots of pressure, temperature and composition.

Ans: B

Q.29 Imperfection arising due to the displacement of an ion from a regular site to an interstitial site maintaining overall electrical neutrality of the ionic crystal is called.
(A) Frenkel imperfection **(B)** Schottky imperfection
(C) Point imperfection **(D)** Volume imperfection

Ans: A

Q.30 The Fermi level is
(A) an average value of all available energy levels.
(B) an energy level at the top of the valence band.
(C) the highest occupied energy level at 0 ^{0}C.
(D) the highest occupied energy level at 0 ^{0}K.

Ans: D

Q.31 Among the common dielectric materials, the highest dielectric strength is possessed by
(A) mica. **(B)** polyethylene.
(C) PVC. **(D)** transformer oil.

Ans: A

Q.32 Annealing is generally done to impart
(A) hardness to the material **(B)** softness to the material
(C) brittleness to the material **(D)** high conductivity to the material

Ans: B

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Q.33 A ferromagnetic material is one in which neighbouring atomic magnetic moments are
(A) antiparallel and unequal.
(B) predominantly parallel.
(C) all randomly oriented.
(D) predominantly parallel in a small region of material.

Ans: B

Q.34 In intrinsic semiconductor there are
(A) no mobile holes.
(B) no free electrons.
(C) as many free electrons as there are holes.
(D) neither free electrons nor mobile holes.

Ans: C

Q.35 Covalent bonding in solids depends primarily on
(A) electrical dipoles.
(B) sharing of electrons.
(C) transfer of electrons.
(D) gravitational forces.

Ans: B

Q.36 Mobility of electron is
(A) Average flow of electrons per unit field.
(B) Average applied field per unit drift velocity.
(C) Average drift velocity per unit field.
(D) Reciprocal of conductivity per unit charge.

Ans: C

Q.37 In a dielectric, the power loss is proportional to
(A) ω.
(B) ω^2.
(C) $\frac{1}{\omega}$.
(D) $\frac{1}{\omega^2}$.
Where ω is the angular frequency of applied electric field.
Ans: A

Q.38 Above curie temperature, the spontaneous polarization for ferro electric materials is
(A) zero.
(B) 1.
(C) $\frac{1}{2}$.
(D) infinity.

Ans: A

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Q.39 Chemical formula of a simple ferrite may be written as

(A) $M_e^{2+} F_{e_2}^{3+} O_4^{2-}$. **(B)** $M_e^{3+} F_e^{4+} O_4^{2+}$.
(C) $M_e^{4+} F_e^{2+} O_4^{3+}$. **(D)** $M_e^{5+} F_e^{4+} O_4^{2+}$.

Ans: A

Q.40 Fermi level represents the energy level with probability of its occupation of

(A) 0 %. **(B)** 25 %.
(C) 50 %. **(D)** 100 %.

Ans: C

Q.41 The acceptor type impurity is formed by adding impurity of valency

(A) 6. **(B)** 5.
(C) 4. **(D)** 3.

Ans: D

Q.42 Which of the following processes is used to harden a steel?

(A) Normalizing **(B)** Annealing
(C) Carburizing **(D)** Quenching

Ans: D

Q.43 If the atomic number of an element is Z, and its atomic mass number is A, the number of protons in its nucleus is

(A) A. **(B)** Z.
(C) A – Z. **(D)** A / Z.

Ans: B

Q.44 Miller indices of the diagonal plane of a cube are

(A) (200). **(B)** (111).
(C) (010). **(D)** (110).

Ans: D

Q.45 Melting point of Cesium and Iridium are $28^\circ C$ and $2455^\circ C$ respectively. In their phase diagrams they are likely to have

(A) solid phase partly.
(B) liquid phase.
(C) solid liquid phase.
(D) all of the above.

Ans: D

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Q.46 The steady state conditions in diffusion are governed by

(A) Fick's second law. **(B)** Fick's first law.
(C) both **(A)** and **(B)**. **(D)** Maxwell-Boltzmann's law.

Ans: B

Q.47 Highest electrical resistivity exists in

(A) platinum wire. **(B)** nichrome wire.
(C) silver wire. **(D)** kanthal wire.

Ans: B

Q.48 For high speed of reading and storing the informations in a computer, the use is made of

(A) ferrites. **(B)** pyroelectrics.
(C) piezo electrics. **(D)** ferromagnetics above $768^\circ C$.

Ans: A

Q.49 Hall effect can be used to measure

(A) mobility of semiconductors. **(B)** conductivity of semiconductors.
(C) resistivity of semiconductors. **(D)** all of these.

Ans: D

Q.50 The unit of dielectric constant is

(A) Dimensionless **(B)** Fm^{-1}.
(C) CV^{-1}. **(D)** Fc^{-1}.

Ans: B

Q.51 The atomic diameter of an FCC crystal having lattice parameter a is

(A) $\frac{a\sqrt{2}}{2}$. **(B)** $\frac{a\sqrt{2}}{4}$.
(C) $\frac{a\sqrt{3}}{4}$. **(D)** $\frac{a}{2}$.

Ans: A

Q.52 A pair of one cation and one anion missing in a crystal of the type AB is called

(A) Schottky defect. **(B)** Frenkel defect.
(C) Pair of vacancies. **(D)** None of these.

Ans: A

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Q.53 The maximum number of co-existing phases in a C-component system is

(A) C – F + 2. **(B)** P(C – 1).
(C) F – C +2. **(D)** C + 2.

Ans: A

Q.54 Pure silicon at zero K is an

(A) intrinsic semiconductor. **(B)** extrinsic semiconductor.
(C) metal. **(D)** insulator.

Ans:D

Q.55 The dielectric strength of a material is the highest

(A) current which can pass through it.
(B) voltage that can be applied to it.
(C) field (voltage per meter thickness) that can be with-stood by it.
(D) current density that can be transmitted by it.

Ans: C

Q.56 A Ge atom contains

(A) four protons **(B)** four valence electrons
(C) six valence electrons **(D)** only two electron orbits

Ans: B

Q.57 The energy required to break a covalent bond in a semiconductor

(A) is equal to 1 eV
(B) is equal to the width of the forbidden gap
(C) is greater in Ge than in Si
(D) is the same in Ge and Si

Ans: B

Q.58 The property of a material by which it can be drawn into wires is known as

(A) ductility **(B)** elasticity
(C) softness **(D)** tempering

Ans: A

Q.59 An electron in the conduction band

(A) is located near the top of the crystal
(B) has no charge
(C) has a higher energy than an electron in the valence band
(D) is bound to its parent atom

Ans: C

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Q.60 At 0° K, all the valence electrons in an intrinsic semiconductor
(A) are in the valence band
(B) are in the forbidden gap
(C) are in the conduction band
(D) are free electrons

Ans: A

Q.61 Malleability of a metal is the
(A) ability to withstand compressive stresses
(B) ability to withstand deformation under shear
(C) property by which a material can be cold-worked
(D) ability to undergo permanent deformation

Ans: C

Q.62 Insulating material used in spark plug is
(A) rubber
(B) porcelain
(C) mica
(D) Polysterene

Ans: B

Q.63 Which of the following has piezoelectric properties:
(A) corundum
(B) neoprene
(C) quartz
(D) glass

Ans: C

Q.64 For metallization, the property not desirable is
(A) reproducibility
(B) quick dissipation of heat
(C) low thermal conductivity
(D) high melting point

Ans: A

Q.65 If P is the number of phases, F is the degrees of freedom, and C is the number of components in a system, then, according to phase rule
(A) $P + F = C - 2$
(B) $P + C = F - 2$
(C) $P + F = C + 2$
(D) $P + C = F + 2$

Ans: C

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Q.66 The correct order of the co-ordination number in simple cubic, body centered cubic and f... centered cubic of unit cell is

(A) 6, 8, 12. **(B)** 8, 12, 12.
(C) 12, 8, 12. **(D)** 6, 8, 8.

Ans: A

Q.67 At absolute zero temperature, the probability of finding an electron at an energy level E is zero when

(A) $E < E_F$ **(B)** $E > E_f$
(C) $E = \frac{E_f}{2}$ **(D)** None

Ans: B

Q.68 A ferromagnetic material is one in which neighbouring atomic magnetic moments are

(A) predominantly parallel in small regions of material.
(B) predominantly parallel and unequal in small regions of material.
(C) predominantly equal and parallel through out the material.
(D) predominantly unequal and parallel throughout the material.

Ans: C

Q.69 In an intrinsic semiconductor, there are

(A) no mobile holes.
(B) no free electrons.
(C) neither free electrons nor mobile holes.
(D) equal number of free electrons and mobile holes.

Ans: D

Q.70 Which one of the following is not the advantage of ion-implantation over diffusion doping

(A) it is a low temperature process.
(B) point imperfections are not produced.
(C) shallow doping is possible.
(D) gettering is possible.

Ans: C

Q.71 The hardness of quenched Martensite

(A) increases with increasing carbon percentage.
(B) decreases as carbon percentage increases.
(C) first increases and then remains almost constant as the carbon percentage increases.
(D) first increases and then decreases as carbon percentage increases.

Ans: C

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Q.72 The preheating of parts to be welded and slow cooling of the welded structure will reduce

(A) cracking and incomplete fusion
(B) cracking and residual stress.
(C) residual stress and incomplete penetration.
(D) cracking and underfill.

Ans: C

Q.73 The degree of freedom when ice water and water vapour coexist in equilibrium is

(A) zero **(B)** one
(C) triple point **(D)** minus one

Ans: A

Q.74 Missing of one cation and one anion in an ionic crystal (having charge neutrality) is called

(A) Frenkel imperfections.
(B) Compositional imperfections.
(C) Electronic imperfections.
(D) Schottky imperfections.

Ans: D

Q.75 The $(\bar{1}\bar{1}\bar{1})$ plane is parallel to

(A) (111) **(B)** $(\bar{1}\bar{1}1)$
(C) $(11\bar{1})$ **(D)** $(\bar{1}1\bar{1})$

Ans: A

Q.76 The probability of occupancy of electrons above Fermi level at T=0°K is

(A) 0 %. **(B)** 25%.
(C) 50%. **(D)** 100%.

Ans: A

Q.77 In a ferroelectric material, the spontaneous polarization vanishes above

(A) Transition temperature. **(B)** Debye temperature.
(C) Fermi temperature. **(D)** Curie temperature.

Ans: D

Q.78 P-type and N-type extrinsic semiconductors are formed by adding impurities of valency

(A) 5 and 3 respectively.
(B) 5 and 4 respectively.
(C) 3 and 5 respectively.
(D) 3 and 4 respectively.

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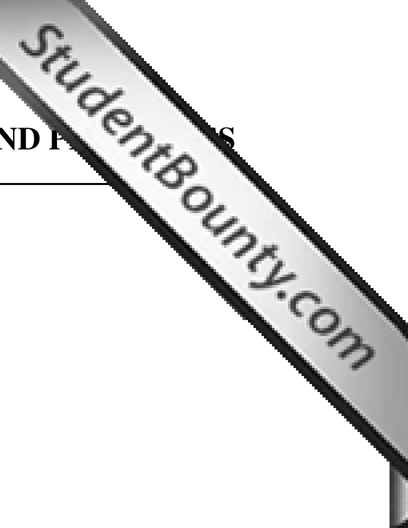

Ans: C

Q.79 Aluminium is not good for die casting because

(A) it is light and strong.
(B) it takes longer time to cool.
(C) it tends to react chemically with the die surface.
(D) its melting point is high and it expands on solidification.

Ans: C

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Code: AE04 MATERIALS AND PROCESS[obscured]

PART – II

NUMERICALS

Q.1 What do you understand by Miller indices of a crystal plane? Show that in a cubic crystal the spacing between two consecutive parallel planes of Miller indices (hkℓ) is given by $d_{hk\ell} = \frac{a}{\sqrt{h^2 + k^2 + \ell^2}}$. **(8)**

Ans:
The labelling of lattice planes by their corresponding reciprocal lattice vectors is called 'Miller indices'.

Here a = b = c

$$d_{hk\ell} = a(h^2 + k^2 + l^2)^{-1/2} = \frac{a}{(h^2 + k^2 + \ell^2)^{1/2}}$$

Q.2 What do you understand by "non-degenerate" and "degenerate" states? Evaluate the temperature at which there is one percent probability that a state, with an energy 0.5 electron volt above the Fermi energy, will be occupied by an electron. **(8)**

Ans:
Different energy levels are defined as having different energies, but more than one quantum state may have the same energy. The no. of states with the same energy is called the degeneracy of the energy level.

$$F(E) = \frac{1}{1 + e^{E - E_F / KT}} \quad \text{Given } E = E_F + 0.5$$

$$= \frac{1}{100} = \frac{1}{1 + e^{0.5/KT}}$$

$$\text{or, } 0.01 = \frac{1}{1 + e^x} \quad | \quad \text{where } x = \frac{0.5}{KT}$$

$$\Rightarrow e^x = 99$$

$$\Rightarrow x = 2.303 \times \log_{10} 99$$

$$\text{or, } \frac{0.5}{KT} = 2.303 \times \log_{10} 99$$

T = 1264 kelvin.

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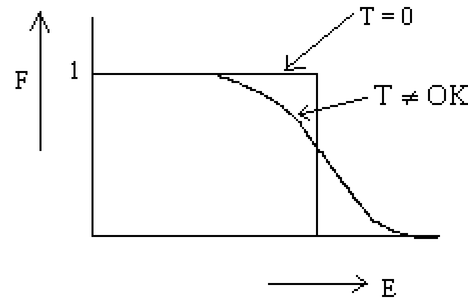
Q.3 Show that the probability of occupancy of energy level E by an electron is 50% for E = E... temperature (T ≠ OK). **(3)**

Ans:

$$F = \frac{1}{1 + e^{\frac{E - E_F}{KT}}}$$

At $E = E_F, T \neq 0, F = \frac{1}{2} = 50\%$.



Q.4 The electrical resistivity of pure silicon is 2300 Ωm at room temperature of 27^0 C, what will be its resistivity at 200^0 C. (Take energy gap = 1.1 eV, K = 8.62 x 10^{-5} eV/K. **(6)**

Ans:

Conductivity, $\sigma = \frac{1}{e} = \frac{1}{2300} = 4.35 \times 10^{-4} (\Omega m)^{-1}$

At T = 27 + 273 = 300K

$$\Rightarrow \frac{E_g}{2KT} = \frac{1.1 \times 10^5}{2 \times 8.62 \times 300} = 21.27$$

At T = 200 + 273 = 473K

$$\frac{E_g}{2KT} = \frac{1.1 \times 10^5}{2 \times 8.62 \times 473} = 13.50$$

$\therefore \sigma_{300} = \sigma_0 e^{-E_g/2KT} = 5.78 \times 10^{-10} \sigma_0$ ....(1)

& $\therefore \sigma_{473} = \sigma_0 e^{-13.58} = 1.37 \times 10^{-6} \sigma_0$ ....(2)

(2)/(1) $\Rightarrow \sigma_{473} = \sigma_{300} \frac{1.37 \times 10^{-6}}{5.78 \times 10^{-10}} = 4.35 \times 10^{-4} \times 0.237 \times 10^4$ = 1.03 $(\Omega m)^{-1}$.

$\therefore$ Resistivity at 473K = $\frac{1}{\sigma_{473}} = 0.97 \Omega m$.

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Q.5 **O**btain the Miller indices of a plane which intercepts at a, b/2, 3c in a simple Cubic unit
Draw a neat diagram showing the plane.(Where a, b, c are lattice parameters) **(6)**

Ans:

(i) The intercepts made by the plane along three crystallographic axes(x, y and z axes).

X	Y	Z
a	b/2	3c
pa	qb	rc

with p = 1, $q = \frac{1}{2}$, r = 3.

(ii) The intercepts as multiples of unit cell dimensions along the axes:

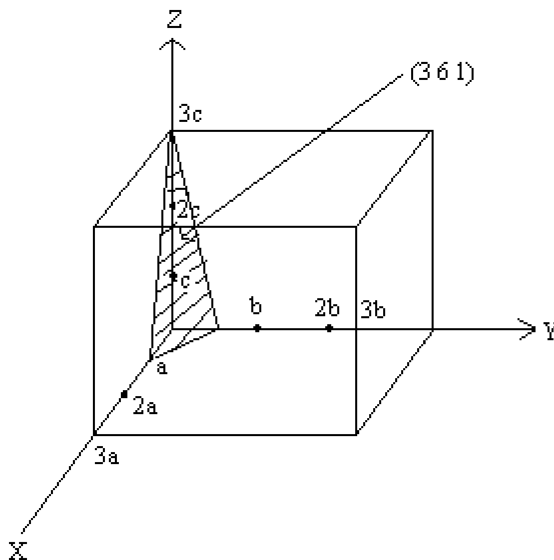
$$\frac{a}{a} \quad \frac{b/2}{b} \quad \frac{3c}{c}$$

i.e. 1 ½ 3

(iii) The reciprocal of these numbers: 1 2 ⅓

(iv) Smallest set of integral numbers of the above reciprocals: 3x1 3x2 $3\times\frac{1}{3}$

3 6 1



Thus the Miller indices of the plane is (3 6 1.) as shown in the figure.

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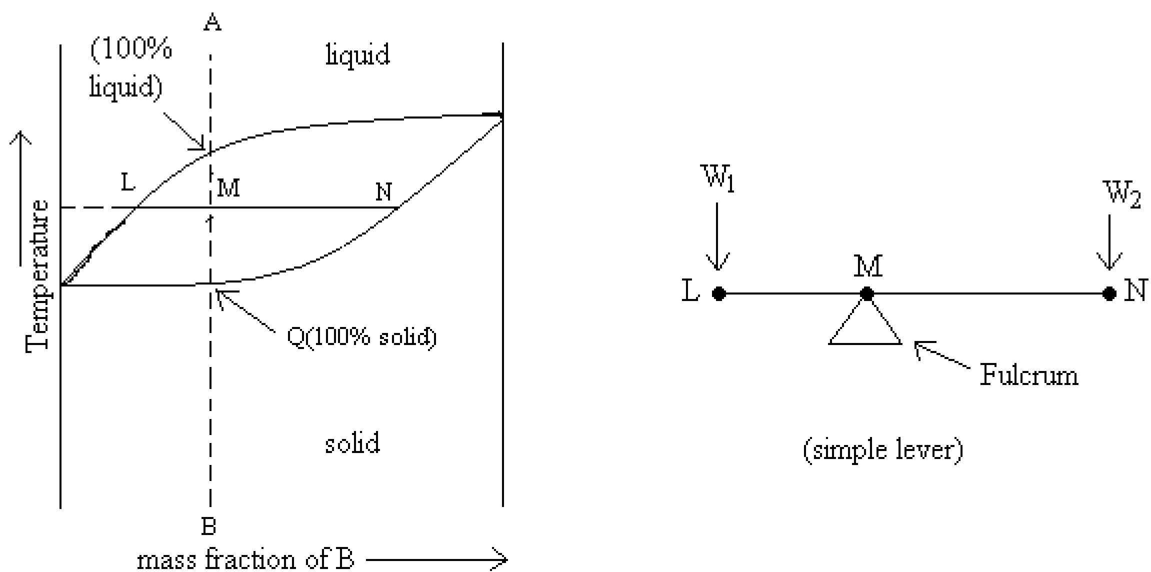
Q.6 What is tie-line rule? Explain. Show that, for correct mass balance, the relative amount of co-existing phases or micro constituents must be as given by the lever rule. **(8)**

Ans:

The tie-line rule is applied to determine the compositions of two co-existing phases in a binary phase diagram. The tie line is a horizontal line drawn at the temperature of interest within the two phase region. The tie line rule is not concerned with phases. It can be applied only in the two phase region. The overall compositions of two co-existing phases remain same on the tie-line. There is change only in their relative amounts which is determined by the lever rule.

The lever rule gives the fractions of two co-existing phases. The composition of each phase can be found by the lever rule.



The vertical line AB is drawn on the composition scale as shown in the fig. Intersection of this line(point M) with the temperature line (tie line) is the fulcrum of simple lever arm. The length LM and MN indicate the amount of solid and liquid respectively.

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Where LM + MN = LN = Total composition of an alloy at temperature t.

$$\% \text{ of solid present} = \frac{LM}{LN}\times 100 = \frac{LN - MN}{LN}\times 100$$

$$\% \text{ of solid present} = \frac{MN}{LN}\times 100 = \frac{LN - LM}{LN}\times 100 .$$

Q.7 Define mobility of a carrier of current How is it related to the Hall coefficient? Is the mobility of an electron in the conduction band of a semiconductor the same as the mobility of an electron(or hole) in the valence band? Give reason for your answer. **(10)**

Ans:

The drift velocity acquired in unit applied electric field is called the mobility(μ) of the carrier,

$$\mu = \frac{V_d}{E}$$

Also, the current density (j) is given by

$$j = n e V_d$$

Where n is the carrier density.
V_d is the drift velocity.
e is the electronic change.

We know that

$$j \,\alpha\, E$$

or, $j = \sigma E$ (from ohm's law)
where σ is the electrical conductivity.

So $n e V_d = \sigma E$

$$\therefore \mu = \frac{V_d}{E} = \frac{\sigma}{ne} = R_H \sigma$$

where $R_H = \frac{1}{ne}$ called hall's coefficient.

μ is also called the Hall mobility.

In conduction band, the electrons are almost free and they can respond to the electric field almost like free electrons. But the electrons in the valence bond are bound to the nuclei. Therefore, their(electrons) response to an applied electric field will be less than that of electrons of the conduction band. Therefore, the mobility of an electron in the valence band is less that that of an electron of the conduction band. This is due to lesser drift velocity for an electron of valence band in comparison to the electrons of conduction band. Similarly, mobility of holes can be explained.

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Q.8 The resistivity of pure silicon at room temperature is 3000 ohm-m. Mobilities of elect[illegible] and holes in silicon are 0.14 $m^2v^{-1}s^{-1}$ and 0.05 $m^2v^{-1}s^{-1}$ respectively. Calculate the intrins[illegible] carrier density of silicon at room temperature. **(6)**

Ans:

The intrinsic charge carriers in pure silicon are electrons and holes in equal numbers. i.e. The intrinsic carrier density is

$$N = n_e = n_h = \frac{\sigma}{(\mu_e + \mu_h)e}$$

Given $\mu_e = 0.14 m^2 v^{-1} s^{-1}$

$\mu_h = 0.05 m^2 v^{-1} s^{-1}$

$\sigma = \frac{1}{e} = \frac{1}{3000} ohm^{-1} m^{-1}$

$$= \frac{1}{(0.14 + 0.05) \times 3000 \times 1.6 \times 10^{-19}}$$

$= 1.095 \times 10^{16} m^{-3}$.

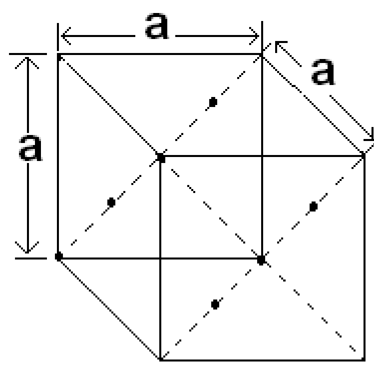
Q.9 Show that the atomic packing factor for FCC and HCP metals are the same. Draw (112) and (120) planes in a fee structure. **(8)**

Ans:

In FCC structure the number of atoms per unit cell are 4 an atomic radius $r = \frac{a\sqrt{2}}{4}$

$$r = \frac{a\sqrt{2}}{4}; \quad \text{APF} = \frac{\text{Volume of atoms per unit cell}}{\text{Volume of unit cell}}$$

$$= \frac{4 \times \frac{4\pi r^3}{3}}{a \times a \times a} = \frac{16\pi \frac{a\sqrt{2}}{4}^3}{3 \times 64 a^3} = \frac{\pi}{3\sqrt{2}} = 0.74$$



FCC

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In HCP unit cell, the corner atoms are touching the centre atom on top and bottom fa
Therefore $a = 2r$ or $r = a/2$

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

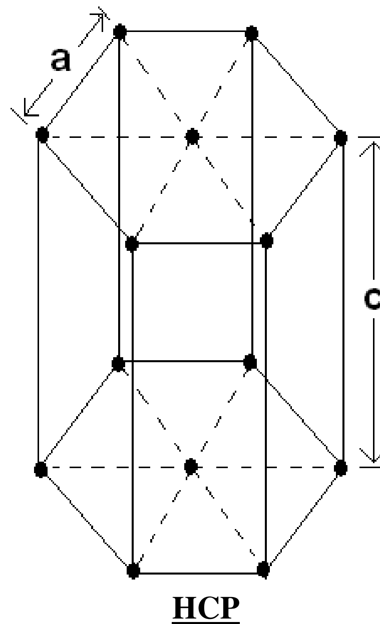
Volume of the hexagon = 33.8767

$$= \frac{6 \times \frac{4\pi r^3}{3}}{3a \sin 60 \times c} = \frac{6 \times \frac{4\pi a^3}{2^3}}{3a^2 \sin 60 \times c} = \frac{\pi a}{3 \sin 60 \times c}$$

Taking c/a ratio for HCP structure = 1.633

$$APF = \frac{\pi}{3 \times 0.866 \times 1.633} = 0.74$$

Thus it is seen that the atomic packing factor for HCP is the same as for an FCC structure.



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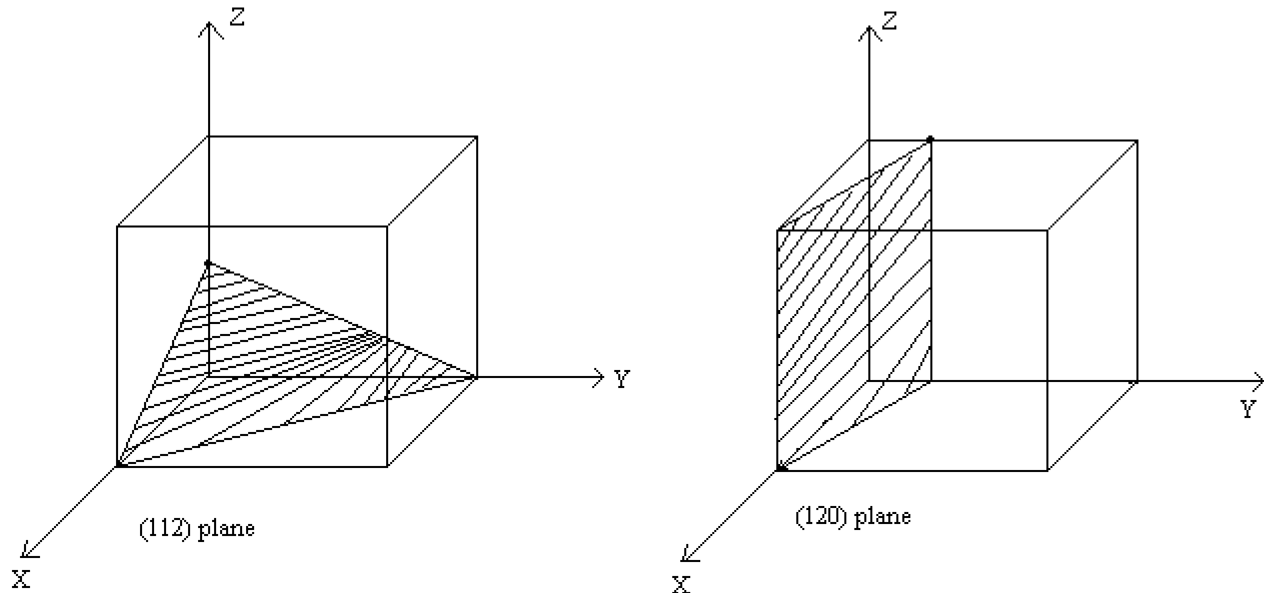
(112) & (120) planes.



Q.10 In a semiconductor the effective mass of an electron is 0.07mo and that of a hole is 0.4mo, where mo is the free electron mass. Assuming that the average relaxation time for the holes is half that for the electrons, calculate the mobility of the holes when the mobility of the electrons is $0.8 m^2 volt^{-1} sec^{-1}$. **(4)**

Ans:
The general expression for mobility is,

$$\mu = \frac{e\tau}{m} \qquad \text{i.e.} \quad \mu_n = \frac{e\tau_n}{m_e^*} \text{ for electrons}$$

$$\& \quad \mu_h = \frac{e\tau_h}{m_h^*} \text{ for holes.}$$

$$\frac{\mu_h}{\mu_n} = \frac{\tau_h m_e^*}{m_h^* \tau_n} = \frac{1}{2} \times \frac{0.07}{0.4}$$

or, $\mu_h = \frac{0.8}{2} \times \frac{0.07}{0.4}$

or, $\mu_h = 0.07 m^2 v^{-1} s^{-1}$.

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Q.11 A 100 μ m diameter wire wound on a cylindrical insulating former of 5 mm diameter, and 5 cm length. If the number of turns is 5 per mm and the resistivity of the material is $2\times10^{-7}\,\Omega-\text{m}$, calculate the resistance of the resistor. **(7)**

Ans: Total no. of turns = 5 * 50 = 250

Length of the wire = 2*π*r *250

= 2*3.14*2.5*250

= 3925mm

= 3.925m

Now Area = $\pi*d^2 / 4$

= $3.14*(100*10^{-6})^2 / 4$

= $0.785*10^{-8}\ m^2$

$\rho = 2 * 10^{-7}\ \Omega\text{-m}$

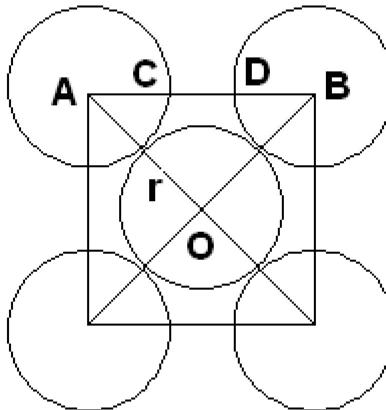
$R = \frac{\rho*l}{A}$

Therefore, $R = \frac{2 * 10^{-7} * 3.925}{0.785*10^{-8}}$

Therefore, R = 100 Ω

Q.12 Show that the maximum radius of the sphere that can just fit into the void at the body centre of the fcc structure coordinated by the facial atoms is 0.414 r, where r is the radius of the atom.

Ans.



r = radius of base atom in fcc crystal.

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From fig. maximum radius of atom which can be fitted in to the crystal is CD/2.

As any face diagonal of fcc = 4 r, hence OA = OB = 2 r.
Thus in rt angle triangle OAB,
$AB = 2\sqrt{2}\ r$
$CD = AB - 2\ r$
$= 2\sqrt{2}\ r - 2\ r$
$= 2\ r\ (\sqrt{2} - 1)$
$= 2\ r \times 0.414$

thus, CD/2 = 0.414 r

Q.13 Find the drift velocity of the free electrons in a copper wire whose cross sectional area (A) is $1\times10^{-6}\,m^{-2}$ when the wire carries a current of 1.0 Amperes. Assume that each copper atom contributes one electron to the electron gas (Given: electron density in copper = 8.5×10^{28} elecrons m^{-3}) **(5)**

Ans: $I = nqV_dA$

$V_d = I/nqA$

$V_d = 1/8.5*10^{28}*1.6*10^{-19}*1*10^{-6}$

$V_d = 1/8.5*1.6*10^{3}$

$V_d = 7.3 * 10^{-5}$ m/sec.

Q.14 Energy gap in germanium is 0.75 ev. Calculate the intrinsic conductivity of germanium at room temperature. (Given : Boltman's constant). **(6)**

Ans: $\sigma_i\ \alpha\ n_i$

$\sigma_i\ \alpha\ \sqrt{A_0*T^3*e^{-E_{G0}/KT}}$

$\sigma_{i27} / \sigma_{i57}\ \alpha\ \sqrt{A_o*(300)^3*e^{-0.75/8.6*10-5*300}} / \sqrt{A_o*(330)^3*e^{-0.75/8.6*10-5*330}}$

$\sigma_{i27} = .866\sigma_{i57}$

Q.15 Find the equilibrium concentrations of vacancies in aluminium at $0^\circ K$, $300^\circ K$ and $900^\circ K$. **(7)**

Ans: i) At 0K

$n/N = \exp\left(-\frac{68*10^3}{8.314*0}\right) = \exp(-\text{infinity}) = 0$

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ii) At 300K

$$n/N = \exp\left(-\frac{68*10^3}{8.314*300}\right) = \exp(-27.36) = 1.45*10^{-12}$$

iii) At 900K

$$n/N = \exp\left(-\frac{68*10^3}{8.314*900}\right) = \exp(-9.12) = 1.12*10^{-4}$$

Q.16 Find the maximum radius of the interstitial sphere that can just fit into the void between the body centred atoms of bcc structure. **(5)**

Ans: In Body centered cubic structure, the atoms touch each other along the diagonal of the cube. Usually, the length of the cell edge is represented by *a*. The direction from a corner of a cube to the farthest corner is called body diagonal (*bd*). The face diagonal (*fd*) is a line drawn from one vertex to the opposite corner of the same face. If the edge is *a*, then we have:

$fd^2 = a^2 + a^2 = 2\,a^2$
$bd^2 = fd^2 + a^2$
$= a^2 + a^2 + a^2$
$= 3\,a^2$

Atoms along the body diagonal (*bd*) touch each other. Thus, the body diagonal has a length that is four times the radius of the atom, *R*.

$bd = 4\,R$
The relationship between *a* and *R* can be worked out by the Pythagorean theorem:
$(4R)^2 = 3\,a^2$
Thus,
$4R = \sqrt{3}a$
or
$R = \sqrt{3}a/4$

Q.17 What are the total variables and degrees of freedom of a system of two components, when the number of phases is one, two, three etc.? **(6)**

Ans: For two – component systems, the degree of freedom can be calculated by the modified phase rule given as:

F = C-P+2
And the total number of variables can be calculated by:
P(C-1) +2

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Therefore,

No. of Phases	Total Variables	Degree of freedom
1	3	3
2	4	2
3	5	1
4	6	0

The System cannot have more than four phases in equilibrium.

Q.18 Derive an expression for the electrical conductivity of a metal on the basis of free electron theory. Explain why nichrome and not copper is used as a heating element. **(6 + 4)**

Ans: Electric field applied across conductor having length **'l'** is

E=V*l

Under any electric field **E**, the drift velocity is $V_d = \mu * E$. Here μ is the mobility of the charge carriers.

G = σ*A/l

Here **σ** is conductivity.

A is the cross-sectional area of the conductor.

l is the length of the conductor.

And **G = I/V = I/E*L**

Here **V = E*l**

So, **σ*A/l = I/E*l**

Or **σ = I/A*E**

The current I is the total charge passing through any cross-section of the conductor $I = n*q*V_d*A$.

So, $\sigma = n*q*V_d*A/A*E = n*q*\mu$

Here, $V_d = \mu*E$

Electrical conductivity is strongly dependent on temperature. In metals, electrical conductivity decreases with increasing temperature, whereas in conductors, electrical conductivity increases with increasing temperature. Nichrome has a higher resistivity, higher tensile strength and low temperature coefficient then copper; and that is why nichrome is used as a heating element.

Q.19 Calcium has a face-centred cubic structure with an ionic radius of 1.06 Å. Calculate the interplanar separation for (111) planes. **(8)**

Ans: $d = a / \sqrt{(h^2 + k^2 + l^2)}$

Here, $a = 1.06 * 10^{-10}$m
And h = k = l = 1

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Therefore, $d_{111} = 1.06 * 10^{-10}\text{m} / \sqrt{(1^2 + 1^2 + 1^2)}$
$= 1.06 * 10^{-10}\text{m} / \sqrt{3}$
$= 0.612 * 10^{-10}\text{m}$

Q.20 Show that for correct mass balance, the relative amounts of two co-existing phases or microconstituents must be given by the lever principle. **(8)**

Ans: Using the **lever rule** one can determine quantitatively the relative composition of a mixture in a two-phase region in a phase diagram. The distances l from the mixture point along a horizontal tie line to both phase boundaries gives the composition:

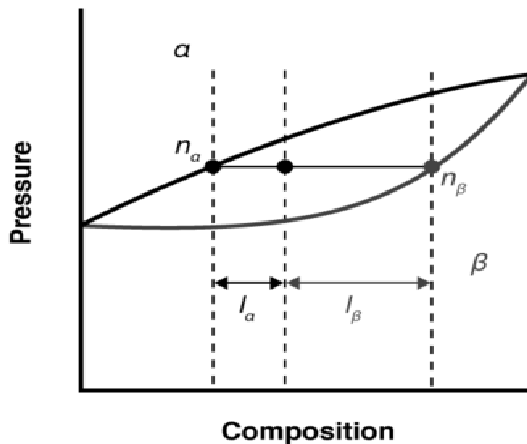
$n_\alpha l_\alpha = n_\beta l_\beta$

n_α represents the amount of phase α and n_β represents the amount of phase β.

It can be conveniently expressed as:

%α=(x*L)/ (α*L)*100

%L= (α*x)/ (α*L)*100



Q.21 What are the similarities and differences of primitive cells and unit cells? What do you understand by Miller indices of a crystal plane?
Derive an expression for the interplaner spacing for planes of (hkl) type in the case of a cubic structure. **(3+2+3)**

Ans: The unit cell is the basic building block of a crystal, repeated infinitely in three dimensions.

It is characterized by the three vectors (*a, b, c*) that form the edges of a parallelopiped and The angles between the vectors (*alpha*, the angle between *b* and *c*; *beta*, the angle between *a* and *c; gamma*, the angle between *a* and *b*).

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A primitive cell is a unit cell built on the basis vectors of a primitive basis of the direct lat[tice] namely a crystallographic basis of the vector lattice **L** such that every lattice vector **t** of **L** ma[y] be obtained as an integral linear combination of the basis vectors, **a**, **b**, **c**. It contains only one lattice point and its volume is equal to the triple scalar product (**a**, **b**, **c**).

Non-primitive bases are used conventionally to describe *centered lattices*. In that case, the unit cell is a multiple cell and it contains more than one lattice point. The multiplicity of the cell is given by the ratio of its volume to the volume of a primitive cell.

Miller Indices are a symbolic vector representation for the orientation of an atomic plane in a crystal lattice and are defined as the reciprocals of the fractional intercepts which the plane makes with the crystallographic axes.

In an orthogonal coordinate system, the interplanar distance d_{hkl} is given by:

$$1 / (d_{hkl})^2 = (h/a)^2 + (k/b)^2 + (l/c)^2$$

Where h, k, l are the Miller indices of the planes and a, b, c are the dimensions of the unit cell.

Now for a cubic system, a = b =c

Therefore, $d_{hkl} = a / [h^2 + k^2 + l^2]^{1/2}$

Q.22 How are p-type and n-type semiconductor obtained? Show that the Fermi energy in an intrinsic semiconductor lies approximately half way between the top of valence band and the bottom of conduction band. When does intrinsic semiconductor become an extrinsic semiconductor? Explain. **(2+4+2)**

Ans: A **P-type semiconductor** is obtained by carrying out a process of doping, that is adding a certain type of atoms to the semiconductor in order to increase the number of free charge carriers (in this case positive). The purpose of **P-type doping** is to create an abundance of holes.

When the doping material is added, it takes away (accepts) weakly-bound outer electrons from the semiconductor atoms. This type of doping agent is also known as *acceptor material* and the semiconductor atoms that have lost an electron are known as *holes*

An **N-type semiconductor** is obtained by carrying out a process of doping, that is, by adding an impurity of valence-five elements to a valence-four semiconductor in order to increase the number of free charge carriers (in this case negative). The purpose of **N-type doping** is to produce an abundance of mobile or "carrier" electrons in the material.

Semiconductor doping is the process that changes an intrinsic semiconductor to an extrinsic semiconductor. During doping, impurity atoms are introduced to an intrinsic semiconductor. Impurity atoms are atoms of a different element than the atoms of the intrinsic semiconductor. Impurity atoms act as either donors or acceptors to the intrinsic semiconductor, changing the electron and hole concentrations of the semiconductor.

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Fermi Level in an Intrinsic Semiconductor

In an Intrinsic Semiconductor, Fermi level (E_f) lies in the middle of energy gap or mid way between the conduction and valence bands.

Let,

n_v = No. of electrons in the valence band

n_c = No. of electrons in the conduction band

N = No. of electrons in both bands

$= n_v + n_c$

After considering some assumptions, Let the zero energy reference level is arbitrarily taken at the top of the valence band.

Therefore, no. of electrons in the conduction band, $n_c = N.P\ (E_g)$

Where P (E_g) = probability of an electron having energy E_g

Fermi-Dirac probability distribution function gives its value as given below:

$$P\ (E) = 1 / 1 + e^{(E - E_F)/KT}$$

Therefore, $$P\ (E_g) = 1 / 1 + e^{(E_g - E_F)/KT}$$

Therefore, $$n_c = 1 / 1 + e^{(E_g - E_F)/KT}$$

Number of electrons in the valance band is

$$n_v = N.P\ (0)$$

By putting E = 0 in the Fermi – Dirac probability distribution function,

$$P\ (0) = 1 / 1 + e^{(0 - E_F)/KT} = 1 / 1 + e^{-E_F/KT}$$

Therefore, $$n_v = N / 1 + e^{-E_F/KT}$$

Now, $N = n_v + n_c$

$$= N / 1 + e^{-E_F/KT} + 1 / 1 + e^{(E_g - E_F)/KT}$$

After Simplification, we get

$$E_F = E_g / 2$$

This shows that in an Intrinsic Semiconductor, Fermi level (E_f) lies in the middle of energy gap or mid way between the conduction and valence bands.

Q.23 There are 13 electrons in an element whose nucleus contains 14 neutrons. Obtain atomic number and atomic weight of this element. If the atomic weight of the isotope of above element is more by 2, calculate the number of protons and electrons in this isotope. **(7)**

Ans: Atomic number = 13

Atomic weight = 27

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The number of electrons and protons will remain same i.e. 13 according to the property of ... isotope.

Q.24 Calculate the ionisation potential of the electron in the first exited state of singly ionised Helium atom is given by the ionisation of the Hydrogen atom to be 13.6 eV. **(7)**

Ans: According to Bohr,
Ionisation potential of an element = (ionisation potential of hydrogen)/ n^2
We know for helium n=2
Hence IP of He = 13.6/ 2^2 = 3.4 eV

Q.25 The Fermi level for potassium is 2.1ev. Calculate the velocity of the electrons at the Fermi level. **(4)**

Ans: $1/2*m*v^2 = 2.1ev$

$1/2*9.1*10^{-31}*v^2 = 2.1*1.6*10^{-19}$

Therefore, $v^2 = .738*10^{12}$

And so, $v = .859*10^6$ m/sec

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Code: AE04 MATERIALS AND PROCESSES
PART –III

DESCRIPTIVES

Q.1 What are the distinguishing characteristics of metallic bonding? Discuss "cohesive energy" and " electron affinity". **(8)**

Ans:
The metallic state can be visualized as an array of positive ions, with a common pool of electrons to which all the metal atoms have contributed their outer electrons. These electrons have freedom to move anywhere within the crystal and make the metallic bonds non-directional.

'Cohesive energy' : In a chemical bond, it is the energy required to dissociate a solid into isolated atoms or molecules as appropriate.

'Electron affinity' : In a system of a neutral atom and an extra electron, when the extra electron is attracted from the infinity to the outer orbit of the neutral atom, the work done is known as electron affinity of the atom.

Q.2 What are the point, line and surface imperfections found in solid materials? Illustrate these imperfections with suitable sketches. **(12)**

Ans:
Point imperfection: They are imperfect point-like regions in the crystal. One or two atomic diameters is the typical size of a point imperfection. A substitutional impurity and an interstitial impurity are examples of point imperfection.

Line imperfection: Displacement with a curved boundary produces a mixed dislocation line at the boundary.

Surface Imperfection: These are two dimensional and refer to a region of distortions that lies around a surface having a thickness of a few atomic diameters.

Q.3 What is the purpose of zone refining? In a binary phase diagram (pressure omitted), what is the maximum number of phases that can coexist for at least one degree of freedom? **(4)**

Ans:
Zone Refining : Zone refining process is based on the fact that the first solid to crystallize in a two component system is generally purer than the liquid as impurity by repeating the sequence of operations a few times.

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Max. no. of Phases: Two

Q.4 What are major differences in the processes and purposes of hardening (by quenching) and tempering? Explain **(7)**

Ans: Tempering is a heat treatment technique for metals and alloys. In steels, tempering is done to "toughen" the metal by transforming brittle martensite into bainite or a combination of ferrite and cementite. Precipitation hardening alloys, like many grades of aluminum and super alloys, are tempered to precipitate intermetallic particles which strengthen the metal.

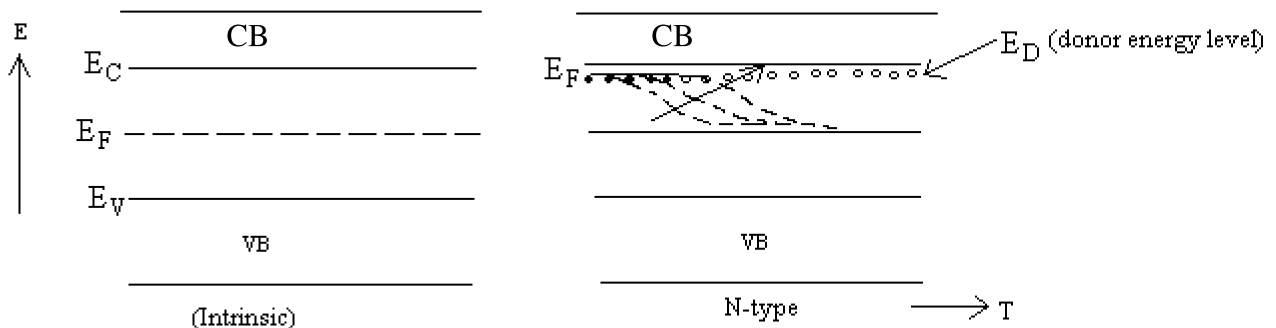
The brittle martensite becomes strong and ductile after it is tempered. Carbon atoms were trapped in the austenite when it was rapidly cooled, typically by oil or water quenching, forming the martensite. The martensite becomes strong after being tempered because when reheated, the microstructure can rearrange and the carbon atoms can diffuse out of the distorted BCT structure. After the carbon diffuses, the result is nearly pure ferrite.

In metallurgy, there is always a tradeoff between ductility and brittleness. This delicate balance highlights many of the subtleties inherent to the tempering process. Precise control of time and temperature during the tempering process are critical to achieve a metal with well balanced mechanical properties.

Quenching is most commonly used to harden steel by introducing martensite, in which case the steel must be rapidly cooled through its eutectoid point, the temperature at which austenite becomes unstable. In steel alloyed with metals such as nickel and manganese, the eutectoid temperature becomes much lower, but the kinetic barriers to phase transformation remain the same. This allows quenching to start at a lower temperature, making the process much easier. High speed steel also has added tungsten, which serves to raise kinetic barriers and give the illusion that the material has been cooled more rapidly than it really has. Even cooling such alloys slowly in air has most of the desired effects of quenching.

Q.5 Indicate on an energy level diagram thee conduction and valence bands, donor & acceptor states and the position of Fermi level for
(i) an intrinsic semiconductor.
(ii) a n-type semiconductor.
(iii) a p-type semiconductor. **(6)**

Ans:



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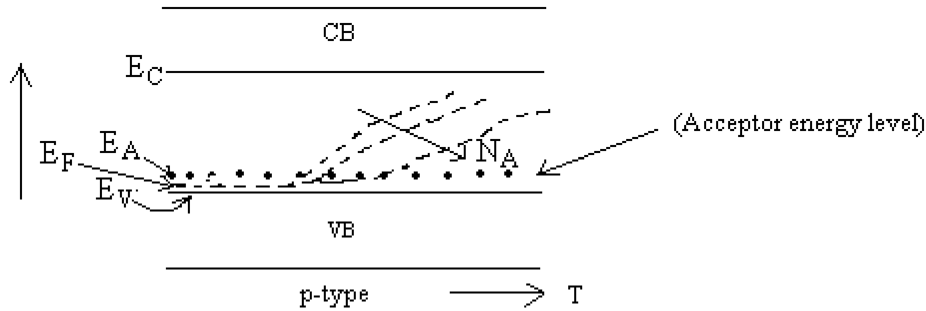

Q.6 What is Hall effect? Briefly discuss the physical origin and uses of Hall effect? **(7)**

Ans:
If a conducting bar is placed in a magnetic field B $\perp$ to its axis and if a current flows through the bar in axial direction, then an electric field E is developed that is $\perp$ to both I and B. This effect is known as Hall Effect.

Its physical origin follows from the Boltzmann Transport phenomenon. It is used to get carrier density and the sign of the carriers involved (whether holes or electrons).

Q.7 Explain the following: **(10)**

(i) dielectric loss (ii) dielectric break down
(iii) local electric field (iv) polarizability.

Ans:
(i) Dielectric loss: These losses occur due to electrons hopping from one lattice site to another in transition metal oxides.

(ii) Dielectric Breakdown: Dielectric Breakdown of a dielectric material is due to the excitation of electrons into the conduction band across the energy gap under conditions of excessive voltage, resulting in an avalanche of conducting electrons and consequent physical breakdown.

(iii) Local electric field: It is the sum of the electric field from external sources and the field of the dipoles within the specimen. It is an idealized field measured under certain specified conditions.

(iv) Polarization: The dipole moment per unit volume of the solid is the sum of all the individual dipole moments within that volume and is called 'Polarization' P of the solid.

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Q.8 Distinguish soft magnetic material from hard magnetic material in respect of hyste[...] losses, eddy current losses & domain wall motion with suitable examples and plots. **(8)**

Ans:
Soft magnetic materials should have low hysteresis losses and low eddy current losses. Easy domain wall motion is the key factor in keeping the hysteresis losses to a minimum. Increasing the electrical resistivity of the magnetic medium reduces eddy current losses. Hard magnetic materials must retain a large part of their magnetization on removal of the applied field. Obstacles to domain wall motion should be provided in permanent magnets so that the energy product high residual induction B_r times larger coercive force H_c is large.

Q.9 What are ferrites and ferrox cubes? How are mixed ferrites prepared for industrial uses? Give an account of the applications of ferrites pointing out their advantages over a ferromagnetic material. **(8)**

Ans:
Ferrites are ceramic compounds containing trivalent metal having three valence electrons, iron and oxide of divalent element i.e., metals having two free electrons e.g., MFe_2O_3 where M indicates transition elements such as Co, Ni, Mn, divalent iron, Zn and Cu. They are mainly refractory materials in which all of the valence electrons can be considered as being tied up in an ionic bonding. They are thus unavailable for construction and unable to generate eddy currents. Eddy currents not only dissipate energy but also dampen mechanical & electrical vibrations. They therefore reduce very much the usefulness of ferromagnetic materials for high frequency applications. The dielectric losses of ferrites are very low at high frequencies because they have electrical resistivity. The ferrites are therefore used as ferromagnetic materials for high frequency applications such as TV tubes, memory devices, high-speed switches, transformers, microwave applications. Mixing powdered oxides, compacting and sintering at elevated temperatures make them.

Q.10 What are the objectives of annealing? Discuss the different annealing processes? Is spheroidising different from annealing? Explain. **(8)**

Ans:
A slow cooling rate from the eutectoid temperature yields course pearlite – a mixture of relatively coarse crystals of ferrite and cementite. Such a slow cooling is called annealing. Here, sufficient time is available for the carbon in the austenite to diffuse and redistribute itself to 0.02% in ferrite and 6.67% in cementite. During annealing, effective transformation temperature is low, where the rate of growth is rapid compared to the rate of nucleation. Thus, spheroidising is obviously different from annealing.

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Q.11 Distinguish with suitable examples & diagrams the following:
(i) Rolling and Forging
(ii) Extrusion and Wire drawing.

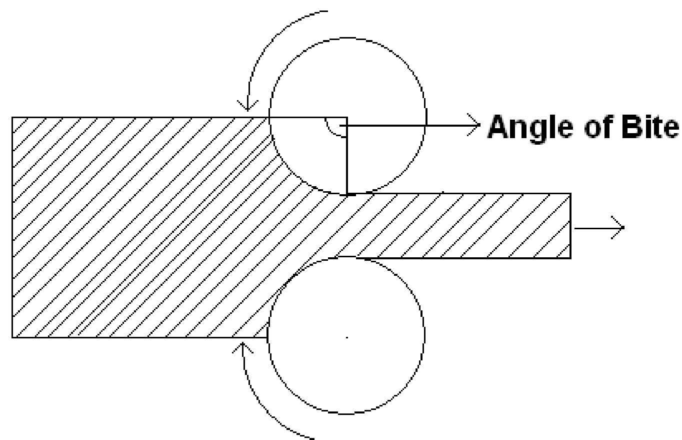
Ans:

(i) Rolling and Forging

Rolling: A pair of cylindrical rollers made of iron or steel rotate in opposite direction with a gap between them which is smaller than the cross section of the piece which is to be rolled. The work piece is inserting into the gap and as it passes between the rolls, it is squeezed, its cross section being progressively reduced. Since the working volume remains constant, the result of passing through the rolls would be lengthening of the work piece and a corresponding reduction and shaping of the cross section.

Rolling provides the cheapest and most efficient method of reducing the cross sectional area of a piece of the material in such a way that the final thickness is uniform throughout the long lengths of the product.

Rolling – Sheets of sheet, plate, strips of material of uniform thickness.



BASIC ELEMENTS OF ROLLING PROCESS

Forging: Forging is shaping of metal either by impact or steady compression between a hammer or ram and anvil. Related to hammering or pressing of metal, the min difference between the two is the speed of pressure application. Hammering process makes use of hammer that is energised by gravity, air or stream and the repeated blows of vertically guided ram on metal resting on the anvil, cause the metal to change its shape.

Cold forging processes are used when it is necessary to develop strength and hardness in a component, have a bright, clean finish, eliminate forging scale, and eliminate decarburisation. This method is used for making bolts, nails nuts.

In the case of hot forging the metal to be forged is heated first. In this case the finish is not bright and clean.

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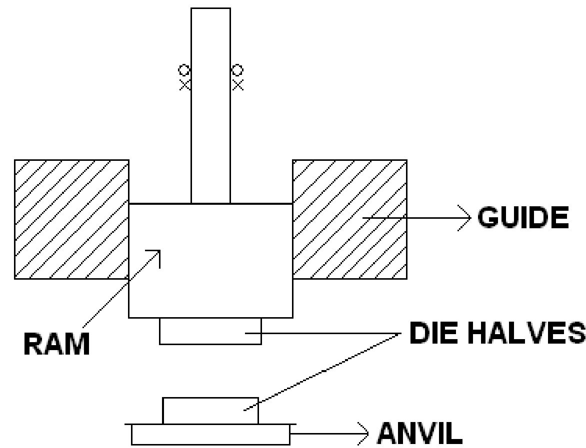
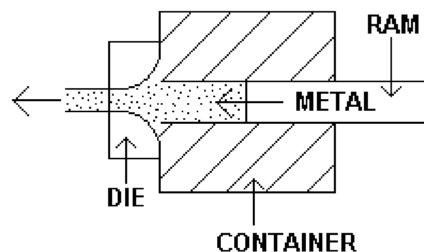
Hot forging is used for making gear, crankshaft, bolts, rivets, and couplings.



DROP FORGING

(ii) Extrusion and Wire drawing-
Extrusion: It is a metal working process that produces long lengths of uniform cross sectional area from a metal billet by causing the latter to flow under hydrostatic pressure through a restricted die or opening. It is mainly a hot working process; starting with cast billets and producing wrought sections and tubes in one stage. It has three major components container, die ram. A heated cylindrical billet is placed in the container and forced out through a steel die by a ram or plunger. Mainly used for manufacturing rods, tubes (circular, rectangular and hollow forms).



EXTRUSION

Drawing: Refers to shaping in a punch press of flat blanks of sheet metal into various shapes. This process is basically forcing the flat sheet of metal into a die cavity with a punch. The force exerted by the punch must be sufficient to draw the metal over the edge of the tie die opening and into the die. The metal flow is similar to a viscous fluid. Deep drawing is a special case of drawing when the length of the object to be drawn is deeper than its width. For example washing machine tubes, aluminium milk churns.

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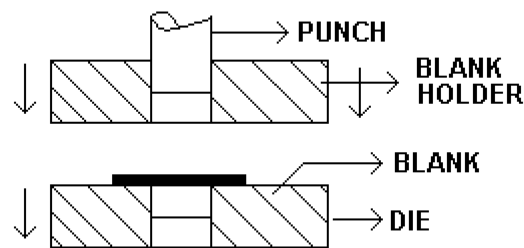

DRAWING

Q.12 Describe briefly the following fabrication processes: **(16)**
(i) Metallization.
(ii) Photolithography.
(iii) Single crystal growth.
(iv) Casting.

Ans:
(i) Metallization: It is the process of providing electrical connections between different parts of the circuit. Aluminium is commonly used. It has a high electrical conductivity and a low melting point for easy evaporation during vacuum deposition.

(ii) Photolithography:
As used in the manufacture of I.C.S, it is the process of transferring geometrical shapes on a mask to the surface of a silicon wafer. Photomask is prepared first.

(iii) Single crystal growth.
The single crystals are grown either by the Czochralski (CZ) method or by the Float Zone (FZ) method. It consists of a furnace with a gradient in temperature. The main parts are crucible, the susceptor, the heating element, power supply and the seed shaft.

(iv) Casting: Fe-C alloys with more than 2% carbon are called cast irons. On crossing the liquidus, proeutectic crystallizes first. On passing through the eutectic temperatures, the liquid of eutectic composition decomposes to a mixture of austerite and Cementite. Further cooling austerite decomposes to pearlite.

Q.13 Why a covalent bond is directional? Describe the salient features of ionic and metallic bonded crystals. **(10)**

Ans: The covalent bond is formed as a result of pairing of two electrons in the atomic orbitals of two atoms. The bond then should lie along the direction of the overlapping of atomic orbital i.e. the bond only occurs in the direction of the shared pairs of electrons. Hence the covalent bonds will have strong directional preferences unlike ionic and metallic bonds.

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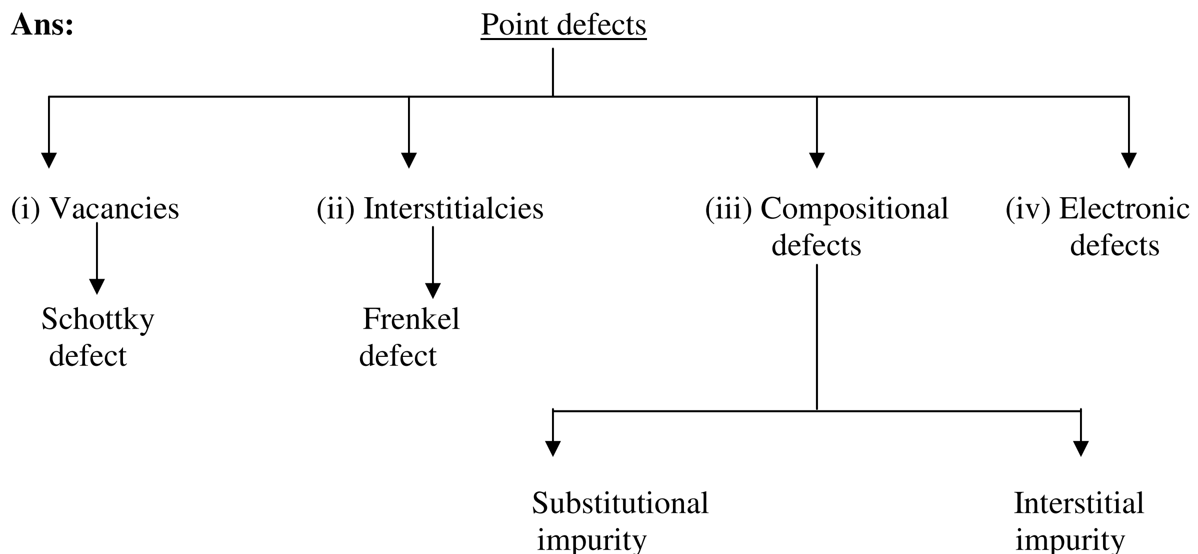
Salient features / Physical properties

Properties	Ionic	Metallic
Bonding Force	The bonds exist due electro-static force of attraction between positive and negative ions of different elements	The bonds exist due to electro-static force of attraction betw-een the electron cloud of valence electrons and positive ions of same or, different metallic elements.
Bond Ionation	Ionic bond is most easily formed when one of the atoms has smaller number of valence elect-rons, such as the alkali metals and alkali earths(by transfer of electrons).	This type of bond is characterist-ic of the elements having small numbers of valence electrons, which are loosely held, so that they can be released to the common pool.
Conduct-Ivity	Low conductivity is the property of solids formed by ionic bonding.	Good thermal and electrical conductivity is the property of most of the solids formed by metallic bonding.
Mechanical Properties	Solids formed have high hardness. Ionic crystals tend to break along Certain planes of crystals rather Than to deform in a ductile fashion When subjected to stresses.	Solids formed mostly have good ductility.
Bond Strength	These bonds are generally stronger than metallic bonds.	These bonds are generally less Stronger than ionic bonds.

Q.14 What are the different types of point defects? How are they caused? **(8)**

Ans:



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(i) Vacancies: This refers to a missing atom or a vacant atomic site due to absence matrix atom.
Missing of one cation and one anion ion in an ionic crystal is scalled Schottky imperfection. Electrical neutrality is maintained in this type of imperfection which is observed in alkali halides.

(ii) Interstitialcies: An extra atom(substantially smaller than the parent atoms) enters the interstitial void or space between the regularly positioned atoms. The vacancy and interestitialcy are, therefore inverse phenomena.
Displacement of cation ions from a lattice site into the void space is called Frankel imperfection and this results in creation of vacancy. An imperfection do not affect the overall electrical neutrality of the crystal.

Compositional defect:

(iii) Substitutional impurity: Presence of foreign atom in place of a matric atom is called substitutional impurity.
If a foreign atom occupies a vacant position within the crystal lattice, this defect is known as interstitial impurity.

(iv) Electronic defects: Errors in charge distribution in solids are termed as electronic defects. There is departure from the normal regularity of charge distribution. This effect is responsible for the operation of p-n junction and transistors.

The point defects formed by

(i) thermal fluctuations during preparation of crystals.
(ii) Quenching(quick cooling) from a higher temperature
(iii) Severe deformation like hammering or rolling.
(iv) External bombardment by atoms or high energy particles(e.g. cyclotron of nuclear reactor).

Q.15 State and explain Fick's law of diffusion. What are the factors influencing the diffusion coefficient? **(10)**

Ans:

Fick's first law states: $\frac{dn}{dt} = DA\frac{dc}{dx}$.

Where $\frac{dn}{dt}$ is the no. of moles crossing per unit time.

A → cross-sectional area perpendicular to direction of diffusion.

$\frac{dc}{dx}$ → concentration gradient in x-direction.

D → the diffusion coefficient and a constant characteristic of the system.

-ve sign indicates that the flow of matter occurs down the concentration gradient. This law is applicable to steady state conditions of diffusion. So the flux(J) (the atoms crossing unit cross-sectional area in unit time) is

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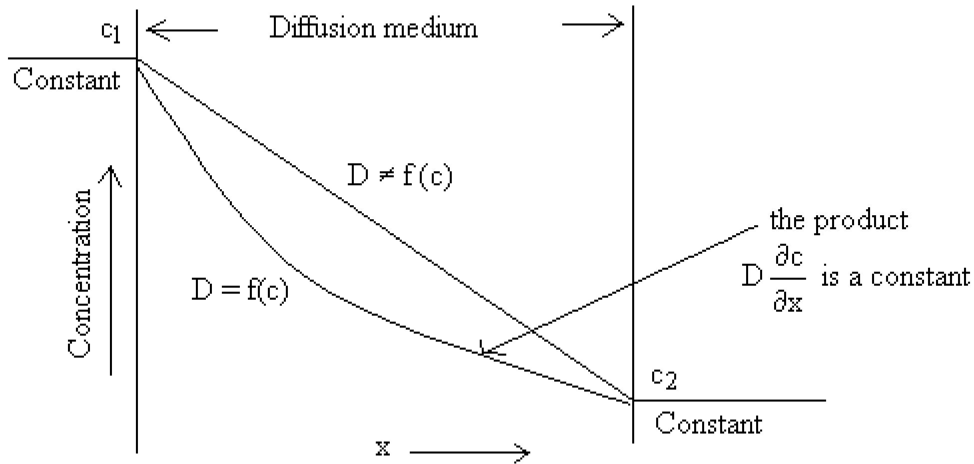
$$J = \frac{1}{A}\frac{dn}{dt} = -D\frac{dc}{dx}$$

Under steady state flux

$$J \neq f(x,t)$$



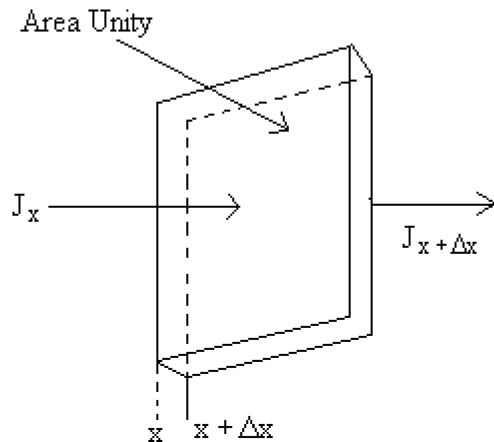
$D \neq f(c) \rightarrow$ straight line profile i.e. D is independent of C.

$D = f(c) \Rightarrow$ product $D\frac{dc}{dx}$ is a constant.

In neither case, the profile changes with time.

Fick's second law: This law is an extension of the first law to non steady state flow. Here, at any instat, the flux is not the same at different cross-sectional planes along the diffusion direction x. Also, at the same cross-section, the flux is not the same at different times. Consequently, the concentration distance profile changes with time.

Consider an elemental slab of thickness Δx and area of cross-section unity



Since area = unity

Volume of slab = Δx

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Under non steady state conditions, the flux into the slab J_x is not equal to the flux o[ut of the] slab, $J_{x+\Delta x}$. The rate of accumulation(or depletion) of the diffusing atoms within this elements volume is $\frac{\partial c}{\partial t}\Delta x = J_x - J_{x+\Delta x}$

$$= J_x - \left(J_x + \frac{\partial J}{\partial x}\Delta x\right)$$

$$\text{or, } \frac{\partial c}{\partial t} = -\frac{\partial J}{\partial x}$$

$$= -\frac{\partial}{\partial x}\left(-D\frac{\partial c}{\partial x}\right)$$

$$= \frac{\partial}{\partial x}\left(D\frac{\partial c}{\partial x}\right)$$

If *D* is independent of concentration, then

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}$$

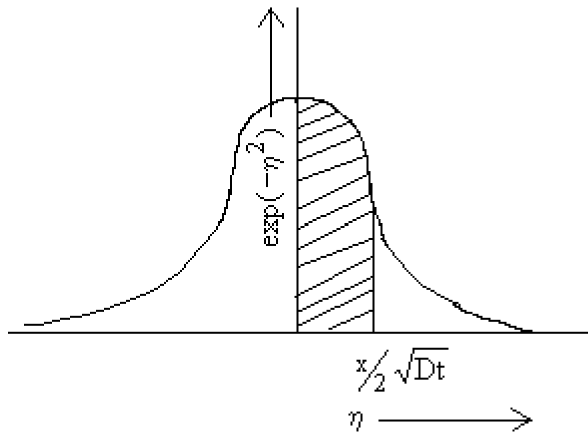
Solution to the above equation for unidirectional diffusion from one medium to another is

$$c(x,t) = A - B\,\mathrm{erf}\,(x/2\sqrt{Dt})$$

Where A and B are constants and error function "erf" is

$$\mathrm{erf}\,\frac{x}{2\sqrt{Dt}} = \frac{2}{\sqrt{\pi}}\int_0^{x/2\sqrt{Dt}} \exp(-\eta^2)\,d\eta$$

Where η is an integration variable.



Various factors influencing diffusion coefficient, *D* are

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(i) Temperature: $D = Ae^{-Q/RT}$

A → frequency factor
Q → activation energy
R → gas constant
T → absolute temperature.

(ii) Pressure: High external pressure is required to change internal condition.
(iii) Crystal structure: Diffusion is much slower in fcc iron than bcc iron.
(iv) Grain boundaries, dislocations and surfaces.
(v) Grain size.
(vi) Concentration..

Q.16 How do temperature and impurities affect electrical resistivity of metals? **(6)**

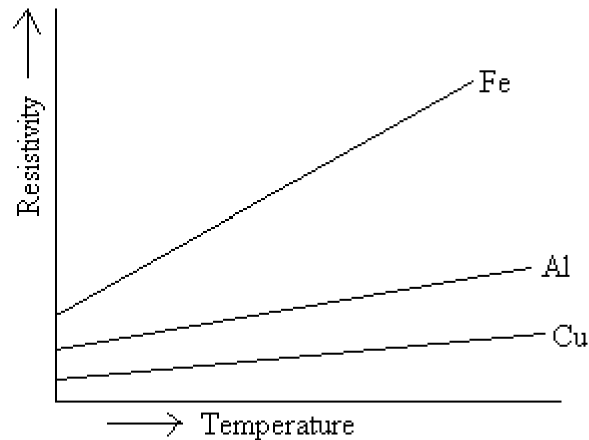
Ans:

Temperature effect on resistivity:

Any increase in temperature of a conductor increases thermal agitation of the metallic ions as they vibrate about their mean positions. This reduces the mean free path and restricts the flow of electrons, thus reducing the conductivity of the material and increasing its resistivity

$P_t = P_\omega[1 + \alpha_0(t - 20)]$

P_t → resistivity at temperature
P_{20} → resistivity at 20^0 c.
α_0 → coefficient of temperature which is positive.



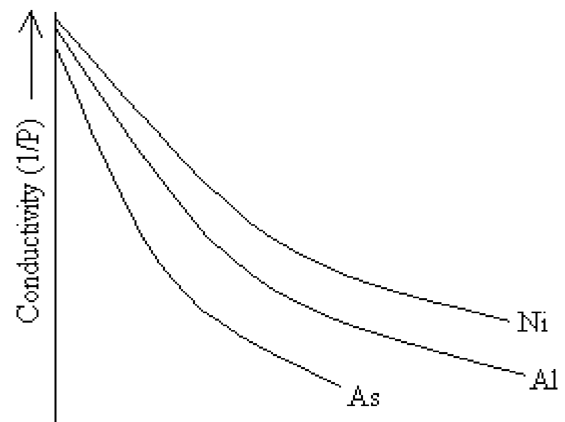
Effect of impurities on resistivity:

A small percentage of impurities can result in significant increase in resistivity i.e. decrease in the conductivity.

Mathematically, it can be represented as

$P_{alloy} = P_{metal} + YP_i$

where P_{alloy} → resistivity of alloy.
P_{metal} → resistivity of parent metal
Pi → resistivity of impurity added



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Q.17 What are properties of an ideal electrical insulating material? What are the various prod and application of mica? **(8)**

Ans:

The following are the properties of an ideal(electrical) insulating material:

(i) Low dielectric court(high dielectric constant if used in capacitors for storing energy.)
(ii) Low power factor.
(iii) High dielectric strength.
(iv) High insulation resistance.
(v) Adequate mechanical strength to face service condition.
(vi) Resistance to heat and temperature.
(vii) Low moisture absorption or water proof.
(viii) Good chemical stability and chemical proof.
(ix) Fire proof.
(x) High volume and surface resistivity.
(xi) Good surface finish and machining.

Products and applications of mica:

(i) Sheet mica: Primarily used in electrical equipment and applications in the form of washers, spacers, sleeves, tubes etc, where high voltages must be withstood. Widely used in high reliability capacitors due to its high dielectric strength are used in microwave window and x-ray tube applications.
(ii) Pasted mica: Prepared by bonding loose mica splittings with various resins and glues into the form of hard plates or flexible sheets. Pasted mica used as flat segment plate in rotary machinery and as moulding plate where complex shapes are required such as commutators, v-rings and channels.
(iii) Mica tape and wrappers: used for insulating high voltage coils, motor armatures and other area of rotating machinery.
(iv) Heater plate: used in percolators and similar commercial appliances.
(v) Reconstituted mica paper: used in high temperature transformers, capacitors and motors.
(vi) Glass bonded mica and ceramoplatics: used in electrical and electronic system where the insulation requirements are preferably low dissipation factor at high frequencies, a high insulation resistance and dielectric breakdown strength along with extreme dimensional stability e.g. telemetering communication plates, moulded printed circuitry relay spacers.

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Q.18 What is dielectric strength? Explain the various causes & processes which give ris... different types of dielectric break down. **(8)**

Ans:

Dielectric strength: It is the maximum voltage / field gradient(voltage per unit thickness) which the dielectric can withstand without failure / breakdown.

Different types of breakdown:

(i) Intrinsic breakdown: It is due to the excitation of electrons into the conduction band across the energy gap under the condition of excessive voltage. The excited electrons can excite more electrons in turns, resulting in an avalanche of conducting electrons. The impurities in the dielectric can create additional energy levels that lie in the energy gap and can help in the excitation of electrons into the conduction band.

(ii) Thermal breakdown: It is due to the attainment of an excessive temperature in the dielectric. If the heat dissipated is less than the heat generated, there is a progressive increase in the temperature of the dielectric, which may melt eventually.

(iii) Defect breakdown: It is due to cracks and pores at the surface. Moisture from the atmosphere can collect on the surface and result in breakdown. Glazing is done on ceramic insulators to make surface non-absorbent.

Q.19 What are the most important properties of permanent magnetic materials? Explain. **(6)**

Ans:

The most important properties of permanent magnetic materials are

(i) Remanence(Residual magnetism(Br):
It is the intensity of the residual magnetism after the magnetism field(H) has been removed.

(ii) Coercive force(H_c):
It is the resistance of magnetic material to demagnetization by electromagnetic techniques.

(iii) Energy product value$(BH)_{max}$:
It is a measure of the amount of magnetic energy stored in a magnet after the magnetising field is removed.

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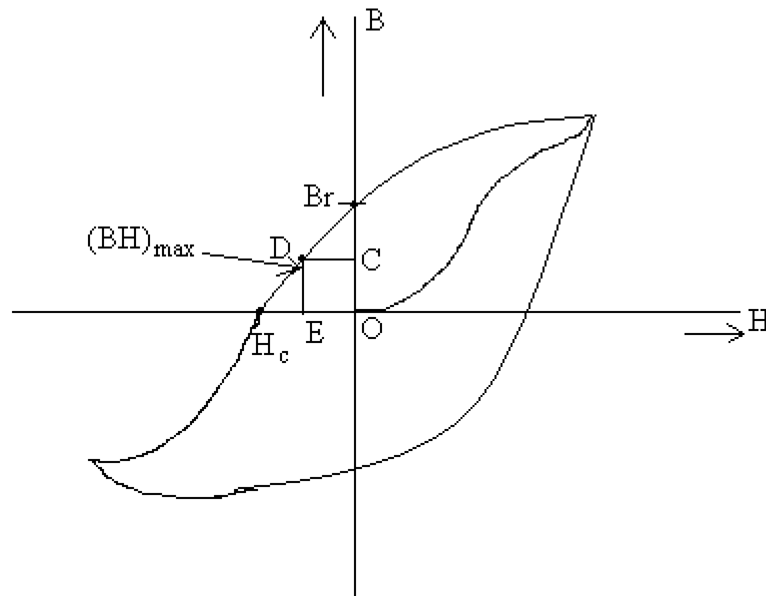

The requirement of permanent magnetic material is that the product of B and H must be maximum possible and it occurs when the product of CD and DE on the demagnetising curve is at a maximum. Depending upon the requirement of remanence and coercive force, the permanent magnetic material is selected.

Q.20 What are ferrites? Where are they used? Give examples. Differentiate magnetically soft ferrites and magnetically hard ferrites. **(10)**

Ans:

Ferrites are ceramic compounds containing trivalent metal having three valence electrons, iron and oxide of divalent element i.e. metals having two free electrons. e.g. $M\,Fe_2O_3$, where M indicates transition elements such as Co, Ni, Mn, divalent iron, Zn and Cu. They are mainly refractory materials with following properties and uses:

(i) A high permeability.
(ii) Very low dielectric loss at high frequencies.
(iii) Very high electrical resistivity(more than $10^{5\Omega}\text{cm}$).
(iv) Low eddy current losses.
(v) High hysteresis loss.
(vi) Brittle in nature.
(vii) Difficult to machine due to brittle nature.

The dielectric losses of ferrites are very low at high frequencies because they have electrical resistivity. The ferrites are therefore used as ferromagnetic materials for high

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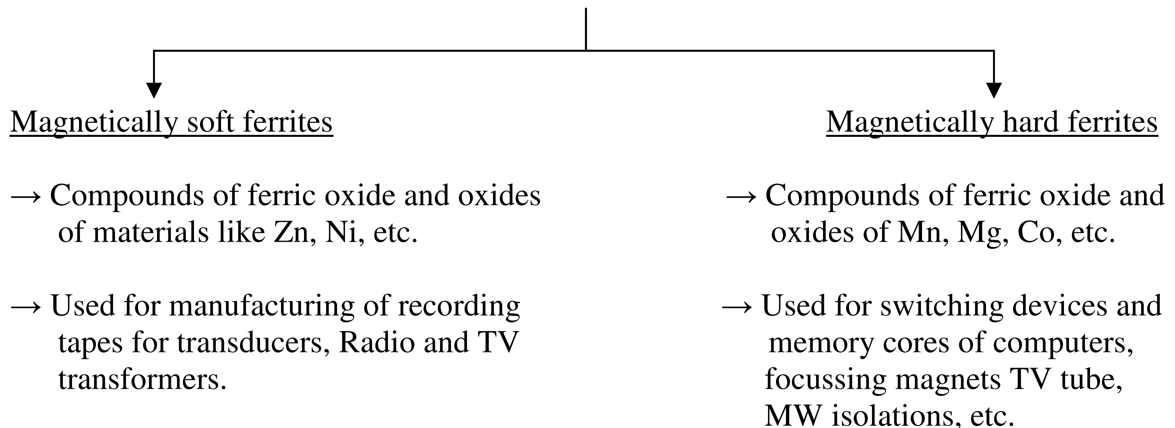
frequency applications such as TV tubes, memory devices, high speed switc
transformers, microwave applications.



Q.21 What is the basis of classification of hot and cold working? What are they advantages and disadvantages of cold working over hot working? **(9)**

Ans:

Cold and hot working:

Changing the shape of material by extrusion, forging, rolling, drawing involves plastic deformation of metals. When the deformation is carried out at temperature below the recrystallization temperature, it is called cold working like cold rolling, drawing, pressing, spinning, impact extrusion.

When the deformation is at temperature higher than the recrystallization temperature the process is known as hot working like forging, rolling, extrusion.

Advantages of cold working

(i) No heat is required.
(ii) Better surface finish is obtained.
(iii) Superior dimension control.
(iv) Improved strength and hardness properties.
(v) Contamination problems are minimised.
(vi) Better reproducibility and interchangeability of parts.
(vii) No loss of metal.

Disadvantages of cold working:

(i) Higher forces are required for deformation.
(ii) Heavier and more powerful equipment is required.
(iii) May produce undesirable residual stresses.
(iv) Not clean and scale free surfaces.
(v) Less ductility is available.
(vi) Strain hardening occurs(required immediately annealing).
(vii) More energy is required than hot working.

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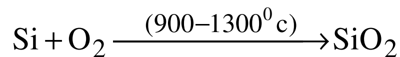
Q.22 What are the functions of oxide layer in high quality IC? Explain. (

Ans:

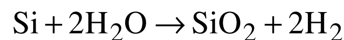
Silicon has the unique ability to be oxidized into silica, which produces a chemically stable, protective and insulating layer on the surface of water.

The functions of the oxide layer are
(i) To mask against diffusion or ion-implant,
(ii) To passivate the surface electrically and chemically.
(iii) To isolate one device from another, and
(iv) To act as a component in MOS devices.

The following reactions occur during thermal oxidation:



$$Si + O_2 \xrightarrow{(900-1300^0 c)} SiO_2$$



$$Si + 2H_2O \rightarrow SiO_2 + 2H_2$$

During oxidation, Si – SiO_2 interface moves into silicon. Also the oxidation process proceeds by the diffusion of the oxidizing species(oxygen ion, oxygen atoms or molecules) through the oxide layer to the Si – SiO_2 interface.

Q.23 Explain the process of extrusion. What are its applications? **(8)**

Ans:

In this process a round heated billet of metal placed in a container is forced out through a die in a press. This process is generally used for manufacture of rods, tubes, brass cartridges, rail, automobile and aircraft parts.
Depending upon the material and the end use there are four different types of extrusions as follows:

(i) Direct extrusion: The billet is placed in a container and forced through the die by a piston .

(ii) Indirect extrusion: The extruded part is first forced through the die and then passes through ram stem. The billet is pressed between the container and the die in case of indirect extrusion. In case of direct extrusion the billet is placed between die and the ram.

(iii) Tube extrusion: The billet is placed inside a container between the die and mandel. The mandel is pressed by ram and the metal is extruded through the die. This process is used for making steel tubes. The billets are heated to about 1300^0c except low carbon steel tubes which are cold worked.

The advantages of this process are
(a) It is comparatively a cheap process.

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(b) Low wall thickness can be obtained by this process.

(iv) Impact extrusion: The blank is placed over the die and pressed by the punch. The metal is squirted upward round the punch. The thickness of the part is fixed by the gap between the punch and the die. This is a cold working process and is mainly used for non ferrous metals like zinc, lead, tin and aluminium alloy for the manufacture of collapsible tubes for shaving cream, tooth pastes etc.

Q.24 What are the objectives of heat treatment processes? Describe the hardening process and explain its various stages. **(8)**

Ans:

The heat treatment is generally adopted for the following:

(i) To refine grain structure
(ii) To improve machinability
(iii) To improve hardness and strength
(iv) To relieve internal stresses developed during cold working, welding, casting, forging etc.
(v) To improve mechanical properties like tensile strength, ductibility and toughness etc.
(vi) To increase heat, wear and corrosion resistance of materials.
(vii) To reduce corrosion rate.
(viii) To improve electrical and magnetic properties.
(ix) To soften metals for further(cold) working as in wire drawing or cold rolling.
(x) To homogenise the structure; to remove coring or segregation.
(xi) To spheroidize tiny particles by diffusion.

Stages of heat treatment process:

All heat treatment processes consist of 3-main steps:

(i) Heating of metal/alloy to the predetermined(definite) temperature.
(ii) Holding(or soaking) of the metal at that temperature for a sufficient period to allow necessary changes(e.g. austenitizing) to occur i.e. structure becomes uniform throughout the section.
(iii) Cooling at a predetermined rate necessary to obtain desired properties associated with changes in nature, form, size and distribution of.

Q.25 Differentiate between “chemical vapour deposition” and “lithography” in the fabrication of ICs. How does addition of copper help in reducing electromigration in the process of metallization? **(6+3)**

Ans:

Chemical vapor deposition (CVD) is a chemical process used to produce high-purity, high-performance solid materials. The process is often used in the semiconductor industry to produce thin films. In a typical CVD process, the wafer (substrate) is exposed to one or more

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volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit. Frequently, volatile by-products are also produced, which are removed by gas flow through the reaction chamber.
Now adding of copper increases the no. of electrons and hence the collisions increase among the electrons. The overall effect results in reducing the electromigration in the process of metallization.

Whereas **Photolithography** (also called optical lithography), which is one of the kinds of lithography is a process used in micro fabrication to selectively remove parts of a thin film (or the bulk of a substrate). It uses light to transfer a geometric pattern from a photo mask to a light-sensitive chemical (photo resist, or simply "resist") on the substrate. A series of chemical treatments then engraves the exposure pattern into the material underneath the photo resist. In a complex integrated circuit (for example, modern CMOS), a wafer will go through the photolithographic cycle up to 50 times.

Q.26 Explain the mechanism of ferromagnetism. On the basis of this explanation how will you explain hystereris and curie point? Describe the experimental evidence to demonstrate the existence of ferromagnetic domains. **(2+4+2)**

Ans:

Ferromagnetism is the basic mechanism by which certain materials (such as iron) form permanent magnets and/or exhibit strong interactions with magnets.

Thus, an ordinary piece of iron generally has little or no net magnetic moment. However, if it is placed in a strong enough external magnetic field, the domains will re-orient in parallel with that field, and will remain re-oriented when the field is turned off, thus creating a "permanent" magnet. This magnetization as a function of the external field is described by a hysteresis curve. Although this state of aligned domains is not a minimal-energy configuration, it is extremely stable and has been observed to persist for millions of years in seafloor magnetite aligned by the Earth's magnetic field (whose poles can thereby be seen to flip at long intervals). The net magnetization can be destroyed by heating and then cooling (annealing) the material without an external field, however.

As the temperature increases, thermal motion, or entropy, competes with the ferromagnetic tendency for dipoles to align. When the temperature rises beyond a certain point, called the Curie temperature, there is a second-order phase transition and the system can no longer maintain a spontaneous magnetization, although it still responds paramagnetically to an external field. Below that temperature, there is a spontaneous symmetry breaking and random domains form (in the absence of an external field). The Curie temperature itself is a critical point, where the magnetic susceptibility is theoretically infinite and, although there is no net magnetization, domain-like spin correlations fluctuate at all length scales.

Q.27 Explain with suitable diagrams the lever rule and Tie-line rule. Why there are tie lines for 3 phase equilibrium but not for 2-phase equilibrium in a two-component system? **(8)**

Ans:

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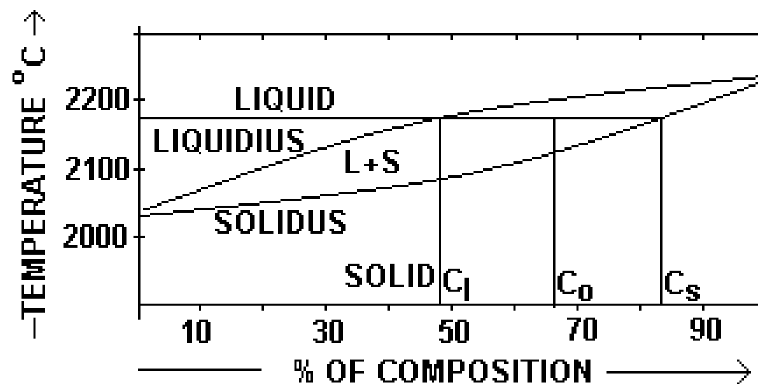
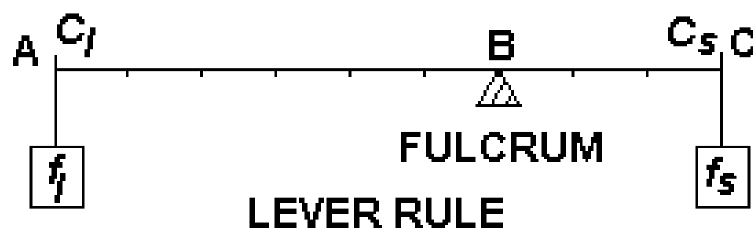
The compositions of two coexisting phases of a binary system are given by tie-line rule. overall composition that lies on the tie line, the composition of the two phases remains th same, c_s and c_i. A little reflection will show that this will be possible only if the relative amounts of the co-existing phases change, as the overall composition is varied along the tie line. It is a horizontal line drawn temperature of intersects within the two-phase region. If for example a liquid phase and a solid phase co-exist at a temperature T, the intersection of the tie-line drawn at that temperature with the liquids gives the composition of the liquid, and the intersection with the solids gives the composition of the solid. It can be applied only in the two-phase region. For overall compositions that lie on the tie line the composition of the two co-existing phases remain the same. There is change only in their relative amounts.



Lever rule derived from mass balance gives the relative amounts of the co-existing phases. It is applied as follows – the tie line is treated as a lever arm, with the fulcrum at the overall composition. For the arm to be horizontal, the weight to be hung at each end must be proportional to the arm length on the other side of the fulcrum. The weight at each end corresponds to the amount of the phase at that end. At temperature T and overall composition co, the relative amounts of the liquid and the solid phases are determined as follows – Expressing the weight fractions of liquid and solid as f_i and f_o

$$f_i = \frac{CB}{CA} = \frac{c_s - c_o}{c_s - c_l} = \frac{82-73}{82-57} = 0.36$$

$$f_s = \frac{BA}{CA} = \frac{c_o - c_l}{c_s - c_l} = \frac{73-57}{82-57} = 0.64$$



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Q.28 What are the main sources of electrical resistance in a metal? Discuss the effect of impu[illegible] temperature and alloying on the electricity conductivity of metal. **(10)**

Ans: The factors that affect the electrical resistance of a metal are impurity, temperature and alloying. The free mean path of an electron is the mean distance it travels between successive collisions. For an ideal crystal with no impurities and imperfections the mean free path at 0 K is infinite. That is, there are no collisions and the electrical conductivity is ideally infinite. Introduction of solute atoms into the crystal results in collisions, decreasing the mean free path and the conductivity. At temperatures above 0 K the atoms vibrate randomly about their mean positions. These vibrations, destroys the initial periodicity of a crystal and interferes with the electron motion. Consequently, the free mean path and conductivity decreases, with increasing temperature. Pure metal has less electrical resistivity than alloys. Alloys have a higher electrical resistivity. As resistivity increases the conductivity decreases.

Q.29 Explain why nichrome and not copper is used as heating element where as manganin is used as standard resistance. **(6)**

Ans:

For heating elements, the primary requirements are high melting point, high electrical resistance and low thermal expansion. The last two requirements help in reducing thermal fatique due to repeated heating and cooling. The heating elements should be designed in a way as to allow unhindered expansion and contractions for example, in the form of a coil of wire. Nichrome (80% nickel & 20% chromium) has all above, mentioned requirements and can be used up to 1300°C. So, nichrome and not copper is used as heating element. Also the melting point of copper is 1083°C, which is less than nichrome.

For resistor applications, the primary requirements are uniform resistivity, stable resistance, small temperature coefficient of resistance and low thermoelectric potential with respe t to copper. A small α minimizes the erron in measurement due to variations in ambient temperature. α is defined as $\alpha = 1/R= dR/dT$ where R is the resistance of the alloy at temperature T. For Manganin alloy (87% copper and 13% manganese) α is only 20 x 10^{-6}/K as against 4000x10^{-5}/K for pure copper. Hence manganin is used as standard resistance.

Q.30 Distinguish between intrinsic and extrinsic semiconductor. Obtain an expression for the carrier concentration for an intrinsic semi-conductor. Also show that the Fermi level in an intrinsic semiconductor lies approximately half way between the top of valence band and the bottom of conduction band. **(12)**

Ans: In intrinsic semiconductors, the conduction is due to the intrinsic processes characteristics of the crystal, without the influence of impurities. A pure crystal of silicon or germanium is an intrinsic semiconductor. The electrons that are excited from the top of the valence band to the bottom of the conduction band by the thermal energy are responsible for conduction. The number of electrons excited across the gap can be calculated from the Fermi-Dirac probability distribution. In extrinsic semiconductors, the conduction is due to the presence of extraneous impurities. The process of deliberate addition of controlled quantities of impurities to a pure semiconductor is called doping. The addition of impurities

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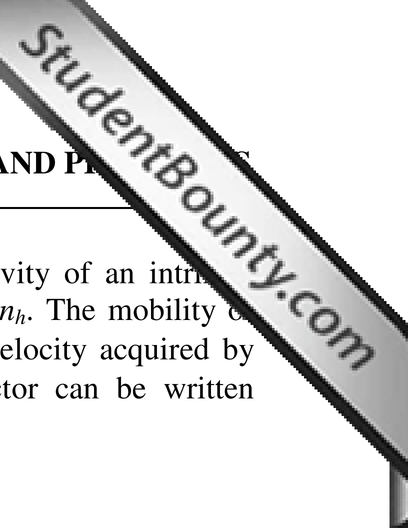
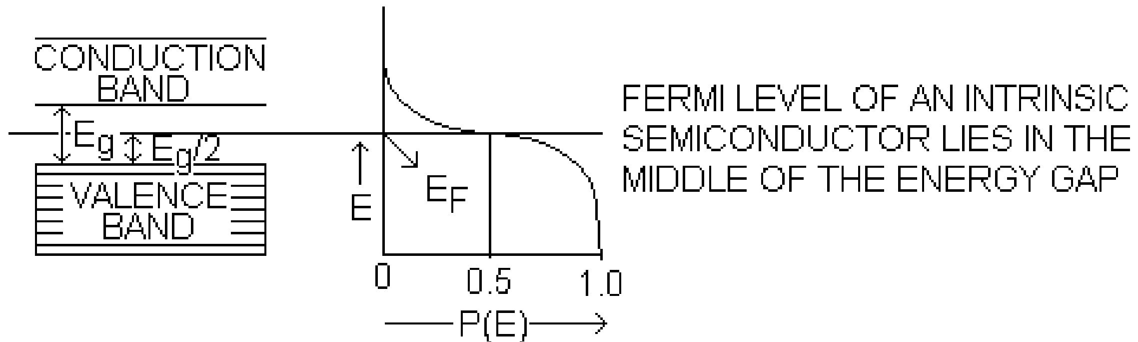


markedly increases the conductivity of a semiconductor. The conductivity of an intri semiconductor depends on the concentration of charge carriers, n_e and n_h. The mobility o conduction electrons and holes μ_e and μ_h can be defined as the drift velocity acquired by them under unit field gradient. The conductivity σ of a semiconductor can be written $\sigma = n_e e\mu_e + n_h e\mu_h$, if $n_e = n_h = n = \dfrac{\sigma}{(\mu_e + \mu_h)e}$



Q.31 Explain the term 'depletion layer' across a p-n junction. How does a p-n junction function as a rectifier? Explain qualitatively. **(8)**

Ans:
The rectifying action of p-n diode can be explained on the basis of the electronic structure of the semiconductor. When a pure semiconductor is doped to become n-type, the Fermi level shifts up from the middle of the energy gap towards the donor level. This is so because the position corresponding to 505 probability of occupation moves up due to the relatively high concentration of donor electrons in the conduction band. If the crystal is p-type, the Fermi level shifts down towards the acceptor level. When the same crystal is doped to become n-type on one side and p-type on the other side, the Fermi level has to be constant throughout the crystal in thermal equilibrium. This results in the electron energy levels at the bottom of the conduction band in the n-part to be lower than those in the p-part, by an amount equal to the contact potential eV_o as shown in Fig a. The contact potential at the junction gives rise to energy barrier or depletion layer.

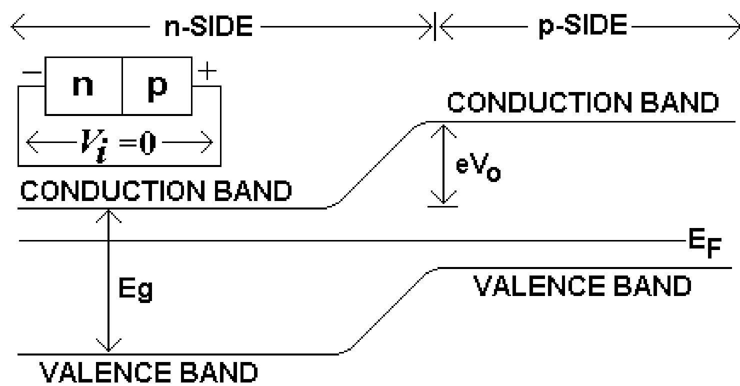


Fig. a

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At equilibrium, there is no net current flowing across the p-n junction. The concentration electrons in the conduction band in the conduction band on the p-side is small. These electrons can accelerate down the potential hill across the junction to the n-side resulting in a current I_o, which is proportional to their number. The concentration of electrons in the conduction band on the n-side is large in comparison, due to the donor contribution. However, only a small number of these electrons can flow to the p-side across the junction as they face a potential barrier.

If an external voltage V_i is now applied to the crystal such that the p-side becomes positive with respect to the n-side the electron energy levels will change as shown in Fig b. The barrier at the junction is now lowered by an amount eV_i resulting in a greatly enhanced current flow in the forward direction that is from the n-side to p-side. This change is barrier does not affect the flow of electrons in the reverse direction, from the p-side to the n-side, as the flow here is still down the potential hill. So the applied voltage causes a large net current flow in the forward direction. If an external voltage V_i is applied in the reverse direction the potential barrier for electrons at the junction is increased by an amount eV_i as shown in Fig.c.

This would drastically reduce the current flow from the n-side to p-side. It is seen that the forward current increases exponentially and the reverse current remains a constant at a small value. This characteristic explains how a p-n junction can act as a rectifier.

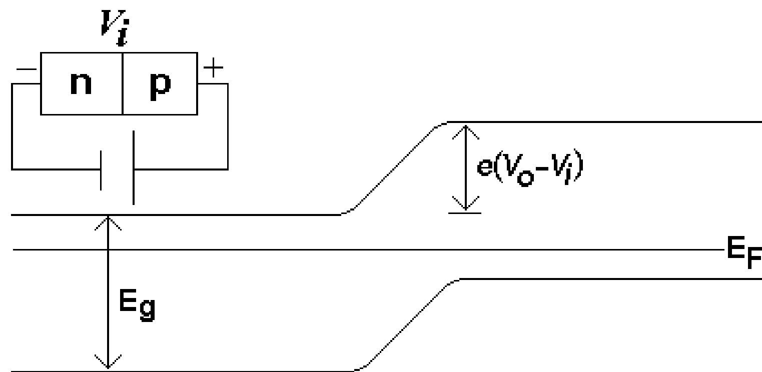

Fig. b FORWARD BIAS

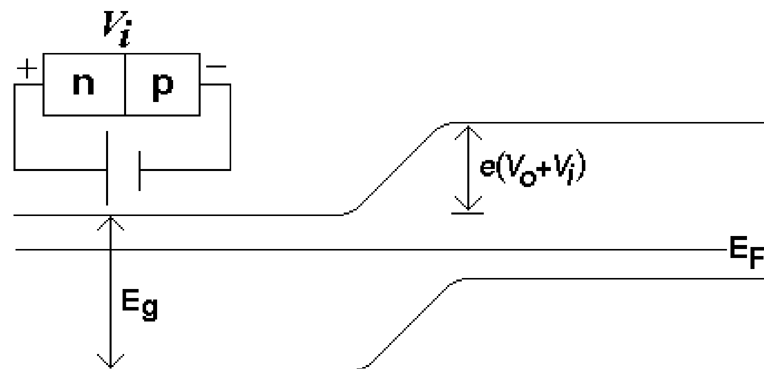

Fig. c REVERSE BIAS

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Q.32 What is piezoelectricity? What are different applications in which piezoelectricity is used? Describe materials that show piezoelectricity. **(8)**

Ans:
Piezoelectricity: Piezoelectricity provides us a means of converting electrical energy to assume new geometric positions and the mechanical dimensions of the substance are altered. This phenomenon is called electrostriction. The reverse effect i.e. production of polarization by the application of mechanical stresses can take place only if the lattice has no center of symmetry, this phenomenon is known as piezoelectricity. Example – Rochelle salt, Quartz, Barium titante.

Applications: Piezoelectric materials serve as a source of ultrasonic waves. At sea, they may be used to measure depth, distance of shore, position of icebergs, submarines. They are also used in microphones, phonograph pickups, and strain gauges.

Q.33 How does B-H hysteresis curve be understood in terms of domain growth and domain rotation? Explain how a high initial permeability in Fe-Ni alloys helps to reduce the area under the hysteresis loop. **(10)**

Ans:
There are two possible ways to align a random domain structure by applying an electric field. One is to rotate a domain in the direction of the field and the other is to allow the growth of the favourably oriented domains at the expense of the less favourably oriented ones. If the domain structure is compared with the grain structure of a polycrystalline material, the boundaries separating the domains called domains walls are the analogue of grain boundaries. The domain boundary energy is about 0.0002 J/m^2 . The domain walls however are some two orders of magnitude thicker than the grain boundaries, because there is a gradual transition from one domain orientation to the next across the wall. Also the domain boundaries can exist within the grain. Analogous to grain growth, the domain walls can move such that the more favourably oriented domains grow at expense of others. In the earlier stages of magnetization below the saturation region of the hysteresis curve, domain growth is dominant. The growth is more or less complete as the saturation region is approached. Therefore the most favourably oriented fully-grown domain tends to rotate so as to be in complete alignment with the field direction. The energy required to rotate an entire domain is more than that required to move the domain walls during growth. Consequently the slope of the B-H curve decreases on approaching saturation.

Q.34 Distinguish ferromagnetic, ferromagnetic and anti-ferromagnetic materials. Give an example of each class of material. Discuss the various uses of ferrites. **(6)**

Ans:
Ferromagnetic materials are those for which k susceptibility is large and positive. These are strongly attracted by the magnetic field. Examples are iron, cobalt, nickel etc.

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An important feature of ferromagnetic materials is that they can retain their magnetism even after the magnetising field has been removed, i.e. they can become permanent magnets.

Ferromagnetic materials are those with spontaneous magnetic alignment. Ferromagnetism is the property of a material to be strongly attracted to a magnetic field and to become a powerful magnet.

Antiferromagnetic materials are the materials in which almost all magnetic dipoles are linked up antiparallel to each other. Its susceptibility increases with increase in temperature, until a critical temperature is reached, beyond which it becomes paramagnetic. Some of the materials are MnF_2, MnO_2, MnS. These too are hardly used in electrical application.

The ferrites are used as ferromagnetic materials for high frequency applications such as TV tubes, memory devices, high-speed switches, transformers, microwave applications. Mixing powdered oxides, compacting and sintering at elevated temperatures make them.

Q.35 What are the objectives of heat treatment of metals? What precautions are necessary while heat-treating to avoid defects? What are the effects of tempering on the mechanical properties of steel? **(9)**

Ans:
Objectives of heat treatment-
Cause relief of internal stresses developed during cold working, welding, casting, forging etc. Harden and strengthen metals. Improve machinability. Change grain size. Soften metals for further working as in wire drawing or cold rolling. Improve ductility and toughness.

Increase, heat, wear and corrosion resistance of materials. Improve electrical and magnetic properties. Homogenise the structure to remove coring or segregation. Spheroidize tiny particles, such as those of Fe_2C in steel, by diffusion.

Some of the precautions to be carried out while heating are –
The metal/alloy has to be heated to a definite temperature. Holding at that sufficient temperature to allow the change to occur.
Tempering relieves residual stresses, improves ductility. Improve toughness, and reduces hardness increase % elongation.

Q.36 In what manner hot worked and cold worked products differ? Describe the hot and cold forging. Compare their properties and economics. **(7)**

Ans:
Hot working of a metal is carried out above its re-crystallization temperature. In this case the metal is not strain hardened. Hot worked products have a refined grain structure. Surface finish of hot worked metal not nearly as good as cold working because of oxidation and scaling. Hot worked products are free from blowholes, internal porosity, and cracks. Hot worked products are more ductile.

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Cold working of a metal is carried out below its re-crystallization temperature. In this c[...] the metal is strain hardened. Cold worked products have a distorted grain structure. Surfac[e] finish of cold worked metal is good. Cold worked products may have cracks. Cold worked products are less ductile.

Forging is shaping of metal either by impact or steady compression between a hammer or ram and anvil. Related to hammering or pressing of metal, the main difference between the two is the speed of pressure application. Hammering process makes use of a hammer that is energised by gravity, air or steam and he repeated blows of vertically guided ram on metal resting on the anvil, causing the metal to change its shape.

Cold forging processes are used when it is necessary to develop strength and hardness in a component, have a bright, clean finish, eliminate forging scale, and eliminate decarburisation. This method is used for making bolts, nails, nuts.

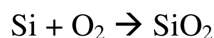
In the case of hot forging the metal to be forged is heated first. In this case the finish is not bright and clean. Hot forging is used for making gear, crankshaft, bolts, rivets and couplings.

Q.37 Write short accounts on the following processes:-

(i) Oxidation in processing of electronic materials.
(ii) Epitaxial growth (CVD).
(iii) Ion implantation.
(iv) Soldering and brazing. **(8)**

Ans:

(i) **Oxidation –** Silicon has the unique ability to be oxidized into silica, which produces a chemically stable, protective and insulating layer on the surface of the wafer. The production of high quality IC's requires a high quality oxide layer. The function of the oxide layer is to mask against diffusion or ion-implant, to passiviate the surface electrically and chemically, isolate one device from another and act as a component in MOS devices. Thermal oxidation is the principle technique and is carried out between 900°C and 1300°C in dry oxygen or steam with the following reactions occurring



$Si + O_2 \rightarrow SiO_2$

$Si + 2HO_2 \rightarrow SiO_2 + 2H_2$

(ii) **Epitaxial Growth –** Refers to the growing of a crystal using another crystal as the substrate, such that the atomic arrangement is continuous across the interface without the formation of a grain boundary. Homoepitaxy refers to silicon grown on silicon; the substrate and he grown crystal usually differ in the level and type of doping. Hetroepitaxy refers to a substantially different composition grown on the substrate.

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The two common processes of Epitaxial Growth are the chemical vapour deposition (CVD) and the molecular beam epitaxy.

(iii) Ion Implantation – For doping at lower temperatures than those used in diffusion doping, ion implantation is used. Here ionised – projectile atoms are introduced into the wafer with enough energy to penetrate the surface. Ion implantation is widely used for shallow doping of n+ regions in the n-channel MOSFET and base region of a bipolar transistor.

(iv) Brazing and Soldering – Both soldering and brazing processes are useful for joining two dissimilar metals. Both brazing alloy and solder have lower melting points than the metals to be joined. Filler metal used in soldering has a melting point below 800°F whereas that in brazing has melting point above 800°F. In brazing process, bonding conditions are set up so that a large amount of diffusion will take place in order to strengthen and improve the bond, whereas in soldering diffusion is of secondary importance. Brazing produces joints stronger than those made by soldering and can be used in service at higher temperatures.

Q.38 Discuss Bohr's structure of hydrogen atom? Define excitation and ionisation potentials. **(7)**

Ans: The Rutherford **Bohr model** of the hydrogen atom ($Z = 1$) or a hydrogen-like ion ($Z > 1$), where the negatively charged electron confined to an atomic shell encircles a small positively charged atomic nucleus, and an electron jump between orbits is accompanied by an emitted or absorbed amount of electromagnetic energy $h\nu$. The orbits that the electron may travel in are black circles; their radius increases as n^2, where n is the principal quantum number. The transition depicted here produces the first line of the Balmer series, and for hydrogen ($Z = 1$) results in a photon of wavelength 656 nm (red).
Excitation is an elevation in energy level above an arbitrary baseline energy state.The **ionization potential** of an atom or molecule is the energy required to remove an electron from the isolated atom or ion.

Q.39 Name various types of cubic class of crystalline structures. Explain their characteristics. Give the values of parameters which distinguish them from each other. **(7)**

Ans:

The **cubic crystal system** (or **isometric**) is a crystal system where the unit cell is in the shape of a cube. This is one of the most common and simplest shapes found in crystals and minerals.

There are three main varieties of these crystals, called "simple cubic", "body-centered cubic" (BCC), and "face-centered cubic" (FCC). Note that although the *unit cell* in these crystals is conventionally taken to be a cube, the *primitive* unit cell often is not. This is related to the fact that in most cubic crystal systems, there is more than one atom per cubic unit cell.

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The **simple cubic** system consists of one lattice point on each corner of the cube. Each atom at the lattice points is then shared equally between eight adjacent cubes, and the unit cell therefore contains in total one atom (1/8 * 8). The **body centered cubic** system has one lattice point in the center of the unit cell in addition to the eight corner points. It has a net total of 2 lattice points per unit cell ((1/8)*8 + 1). Finally, the **face centered cubic** has lattice points on the faces of the cube of which each unit cube gets exactly one half contribution, in addition to the corner lattice points, giving a total of 4 atoms per unit cell ((1/8 for each corner) * 8 corners + (1/2 for each face) * 6 faces).

Some of the elementary characteristics of the cubic structures are given below:

	S.C.	**B.C.C .**	**F.C.C.**
Co-ordination number	6	8	12
Atomic radius	a/2	$\sqrt{3}a/4$	$\sqrt{2}/4$
Atoms per unit cell	1	2	4
Atomic Packing Factor	0.52	0.68	0.74

Q.40 Describe various properties and applications of mica and transformer oil. **(3+3)**

Ans: Properties and uses of MICA

Mica has a high dielectric strength and excellent chemical stability, making it a favoured material for manufacturing capacitors for radio frequency applications. It has also been used as an insulator in high voltage electrical equipment. It is also birefringent and is commonly used to make quarter and half wave plates.

Because mica is resistant to heat it is used instead of glass in windows for stoves and kerosene heaters. It is also used to separate electrical conductors in cables that are designed to have a fire-resistance rating in order to provide circuit integrity. The idea is to keep the metal conductors from fusing in order to prevent a short-circuit so that the cables remain operational during a fire, which can be important for applications such as emergency lighting.

Illites or *clay micas* have a low cation exchange capacity for 2:1 clays. K+ ions between layers of mica prevent swelling by blocking water molecules.

Aventurine is a variety of quartz with mica inclusions used as a gemstone.

Pressed Mica sheets are often used in place of glass in greenhouses.

Muscovite mica is the most common substrate for sample preparation for the atomic force microscope.

Some brands of toothpaste include powdered white mica. This acts as a mild abrasive to aid polishing of the tooth surface, and also adds a cosmetically-pleasing glittery shimmer to the

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paste. The shimmer from mica is also used in makeup, as it gives a translucent "glow" to skin or helps to mask imperfections.

Mica sheets are used to provide structure for heating wire (like Kanthal, Nichrome, etc.) in heating elements and can withstand up to 900 °C.

Another use of Mica is in the production of ultra flat thin film surfaces (e.g. gold surfaces) using mica as substrate. Although the deposited film surface is still rough due to deposition kinetics, the back side of the film at mica-film interface provides ultra flatness, when the film is removed from the substrate.

Mica slices are used in electronics to provide electric insulation between a heat generating component and the heat sink used to cool it.

The **Transformer oil** helps cool the transformer. Because it also provides part of the electrical insulation between internal live parts, transformer oil must remain stable at high temperatures over an extended period. To improve cooling of large power transformers, the oil-filled tank may have external radiators through which the oil circulates by natural convection. Very large or high-power transformers (with capacities of millions of KVAs) may also have cooling fans, oil pumps, and even oil-to-water heat exchangers.

Large, high-voltage transformers undergo prolonged drying processes, using electrical self-heating, the application of a vacuum, or both to ensure that the transformer is completely free of water vapor before the cooling oil is introduced. This helps prevent corona formation and subsequent electrical breakdown under load.

Q.41 Discuss the salient properties and uses of common conducting materials. What types of conductors are used in filament and contact materials? **(7)**

Ans: The **various common conducting materials used are:**

1) Copper

Properties

- It's highly ductile and malleable.
- It can be cast, forged, rolled and machined.
- Mechanical working hardens it, but annealing restores it to soft state.
- It is a very good conductor of heat and electricity.

Uses

- Soft copper is used to make a variety of winding wires and conductors for producing cables.
- Hard copper is used to make commutator segments and contact wire.

2) Aluminium

Properties

- It possesses high ductility.
- It can be readily worked by rolling, drawing, spinning, extruding, and forging.
- It has relatively high thermal and electrical conductivities.
- It has the lowest resistance per unit weight

Uses

- The steel reinforced aluminium conductors find extensive use in long transmission

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lines.

- Aluminium conductors are particularly suitable for operation in very high temperatur[e] range.
- It is used in domestic wiring, flexible wires, rotor bars of squirrel cage induction motor.

3) Tungsten

Properties

- It has very poor resistivity.
- It has highest melting point amongst the metals.
- It is very hard and has high boiling point.

Uses

- It is suitable for applications requiring high operating conditions such as lamps and valve filament lamps.
- It is an outstanding material for electrical contacts in certain applications.
- Tungsten contacts are used in battery ignition systems, vibrators, and electric razors.

Materials with high resistivity and high melting points like Carbon, Tantalum, and Tungsten are used for making the filaments.

For contact materials, the factors which affect the choice of the material are contact resistance, contact force, voltage and current. So platinum, palladium, Silver, Gold, Tungsten, Molybdenum, Rhodium are used.

Q.42 Discuss, briefly, various properties and applications of some common dielectric materials. **(7)**

Ans: A **dielectric material** is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic field.

In practice, most dielectric materials are solid. Examples include porcelain (ceramic), mica, glass, plastics, and the oxides of various metals. Some liquids and gases can serve as good dielectric materials. Dry air is an excellent dielectric, and is used in variable capacitors and some types of transmission lines. Distilled water is a fair dielectric. A vacuum is an exceptionally efficient dielectric.

An important property of a dielectric is its ability to support an electrostatic field while dissipating minimal energy in the form of heat. The lower the dielectric loss (the proportion of energy lost as heat), the more effective is a dielectric material. Another consideration is the dielectric constant, the extent to which a substance concentrates the electrostatic lines of flux. Substances with a low dielectric constant include a perfect vacuum, dry air, and most pure, dry gases such as helium and nitrogen. Materials with moderate dielectric constants include ceramics, distilled water, paper, mica, polyethylene, and glass. Metal oxides, in general, have high dielectric constants.

The prime asset of high-dielectric-constant substances, such as aluminium oxide, is the fact that they make possible the manufacture of high-value capacitors with small physical volume.

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But these materials are generally not able to withstand electrostatic fields as intense as low-dielectric-constant substances such as air. If the voltage across a dielectric material becomes too great -- that is, if the electrostatic field becomes too intense -- the material will suddenly begin to conduct current. This phenomenon is called dielectric breakdown. In components that use gases or liquids as the dielectric medium, this condition reverses itself if the voltage decreases below the critical point. But in components containing solid dielectrics, dielectric breakdown usually results in permanent damage.

Q.43 How does "holding or soaking" time affect the properties of steel during heat treatment process?What are the objectives of annealing? **(5+4)**

Ans: Holding or Soaking time can be defined as the time for which prolonged heating of a metal is done at a selected temperature.

Soaking at a lower solution temperature, however, requires longer holding times to achieve adequate solution treatment within the alloy. A higher soaking temperature allows one to shorten the total holding time while still achieving adequate solution treatment within the alloy.

Basically increasing or decreasing the holding or soaking time in any heat treatment process like that of steel affects and modifies the mechanical properties of the material undergoing the heat process. The holding or soaking time varies the hardness of the material and its strength also.

Annealing, is a heat treatment wherein a material is altered, causing changes in its properties such as strength and hardness. It is a process that produces conditions by heating and maintaining a suitable temperature, and then cooling. Annealing is used to induce ductility, relieve internal stresses, refine the structure and improve cold working properties.

Q.44 What are ferrites? Where are they used? Discuss two important applications of ferrites. **(7)**

Ans: Ferrites are a class of chemical compounds with the formula AB_2O_4, where A and B represent various metal cations, usually including iron. These ceramic materials are used in applications ranging from magnetic components in microelectronics.

Ferrites are a class of spinels, materials that adopt a crystal motif consisting of cubic close-packed (FCC) oxides (O^{2-}) with A cations occupying one eighth of the octahedral holes and B cations occupying half of the octahedral holes. The magnetic material known as "ZnFe" has the deceptively simple formula $ZnFe_2O_4$, with Fe^{3+} occupying the octahedral sites and half of the tetrahedral sites. The remaining tetrahedral sites in this spinel are occupied by Zn^{2+}.

Soft ferrites

Ferrites that are used in transformer or electromagnetic cores contain nickel, zinc, or

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manganese compounds. They have a low coercivity and are called **soft ferrites**. Because of their comparatively low losses at high frequencies, they are extensively used in the cores of Switched-Mode Power Supply (SMPS) and RF transformers and inductors. A common ferrite, abbreviated "MnZn" is composed of the oxides of manganese and zinc.

Hard ferrites

In contrast, permanent ferrite magnets (or "hard ferrites"), which have a high remanence after magnetization, are composed of iron and barium or strontium oxides. In a magnetically saturated state they conduct magnetic flux well and have a high magnetic permeability. This enables these so-called *ceramic magnets* to store stronger magnetic fields than iron itself. They are the most commonly used magnets in radios. The maximum magnetic field B is about 0.35 tesla and the magnetic field strength H is about 30 to 160 kilo ampere turns per meter (400 to 2000 oersteds).

Uses

Ferrite cores are used in electronic inductors, transformers, and electromagnets where the high electrical resistance of the ferrite leads to very low eddy current losses. They are commonly seen as a lump in a computer cable, called a ferrite bead, which helps to prevent high frequency electrical noise (radio frequency interference) from exiting or entering the equipment.

Early computer memories stored data in the residual magnetic fields of hard ferrite cores, which were assembled into arrays of *core memory*. Ferrite powders are used in the coatings of magnetic recording tapes. One such type of material is iron (III) oxide.

Ferrite particles are also used as a component of radar-absorbing materials or coatings used in stealth aircraft and in the expensive absorption tiles lining the rooms used for electromagnetic compatibility measurements.

Most common radio magnets, including those used in loudspeakers, are ferrite magnets. Ferrite magnets have largely displaced Alnico magnets in these applications.

It is a common magnetic material for electromagnetic instrument pickups, because of price and relatively high output. However, such pickups lack certain sonic qualities found in other pickups, such as those that use Alnico alloys or more sophisticated magnets.

Q.45 Outline, qualitatively, the domain theory of ferromagnetic materials. How are the domains formed and are influenced by temperature changes? **(7)**

Ans: The long range order which creates magnetic domains in ferromagnetic materials arises from a quantum mechanical interaction at the atomic level. This interaction is remarkable in that it locks the magnetic moments of neighbouring atoms into a rigid parallel order over a large number of atoms in spite of the thermal agitation which tends to randomize any atomic-level order. Sizes of domains range from a 0.1 mm to a few mm. When an external magnetic field is applied, the domains already aligned in the direction of this field grow at the expense of their neighbours. If all the spins were aligned in a piece of iron, the field would be about 2.1 Tesla. A magnetic field of about 1 T can be produced in annealed iron with an external field of about 0.0002 T, a multiplication of the external field by a factor of 5000! For a given ferromagnetic material the long range order abruptly disappears at a certain temperature which

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is called the Curie temperature for the material. The Curie temperature of iron is about 1043

Q.46 Name various types of magnetic materials. List their properties to distinguish them from each other? **(7)**

Ans: The origin of magnetism lies in the orbital and spin motions of electrons and how the electrons interact with one another. The best way to introduce the different types of magnetism is to describe how materials respond to magnetic fields. This may be surprising to some, but all matter is magnetic. It's just that some materials are much more magnetic than others. The main distinction is that in some materials there is no collective interaction of atomic magnetic moments, whereas in other materials there is a very strong interaction between atomic moments.

The magnetic behavior of materials can be classified into the following five major groups:

1. Diamagnetism
2. Paramagnetism
3. Ferromagnetism
4. Ferrimagnetism
5. Antiferromagnetism

Materials in the first two groups are those that exhibit no collective magnetic interactions and are not magnetically ordered. Materials in the last three groups exhibit long-range magnetic order below a certain critical temperature. Ferromagnetic and ferrimagnetic materials are usually what we consider as being magnetic (ie., behaving like iron). The remaining three are so weakly magnetic that they are usually thought of as "nonmagnetic".

1. **Diamagnetism**

Diamagnetism is a fundamental property of all matter, although it is usually very weak. It is due to the non-cooperative behavior of orbiting electrons when exposed to an applied magnetic field. Diamagnetic substances are composed of atoms which have no net magnetic moments (ie., all the orbital shells are filled and there are no unpaired electrons). However, when exposed to a field, a negative magnetization is produced and thus the susceptibility is negative.

2. **Paramagnetism**

In this class of materials, some of the atoms or ions have a net magnetic moment due to unpaired electrons in partially filled orbitals. One of the most important atoms with unpaired electrons is iron. However, the individual magnetic moments do not interact magnetically, and like diamagnetism, the magnetization is zero when the field is removed. In the presence of a field, there is now a partial alignment of the atomic magnetic moments in the direction of the field, resulting in a net positive magnetization and positive susceptibility.

3. **Ferromagnetism**

Unlike paramagnetic materials, the atomic moments in these materials exhibit very strong interactions. These interactions are produced by electronic exchange forces and result in a parallel or antiparallel alignment of atomic moments.

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4. **Ferrimagnetism**

In ionic compounds, such as oxides, more complex forms of magnetic ordering can occur as a result of the crystal structure. One type of magnetic ordering is ferrimagnetism. Magnetite is a well known ferrimagnetic material.

5. **Antiferromagnetism**

If the A and B sublattice moments are exactly equal but opposite, the net moment is zero. This type of magnetic ordering is called antiferromagnetism.

Q.47 What is hysteresis? What does it signify? Sketch the hysteresis loop for a
(i) Transformer core.
(ii) Strong electromagnet.
(iii) Magnetic tape. **(7)**

Ans: Hysteresis is well known in ferromagnetic materials. When an external magnetic field is applied to a Ferro magnet, the atomic dipoles align themselves with the external field. Even when the external field is removed, part of the alignment will be retained: the material has become magnetized.

The relationship between magnetic field strength (H) and magnetic flux density (B) is not linear in such materials. If the relationship between the two is plotted for increasing levels of field strength, it will follow a curve up to a point where further increases in magnetic field strength will result in no further change in flux density. This condition is called magnetic saturation.

If the magnetic field is now reduced linearly, the plotted relationship will follow a different curve back towards zero field strength at which point it will be offset from the original curve by an amount called the remanent flux density or remanence.

If this relationship is plotted for all strengths of applied magnetic field, the result is a sort of S-shaped loop. The 'thickness' of the middle bit of the S describes the amount of hysteresis, related to the coercivity of the material.

Hysteresis signifies the lagging of magnetization or induction flux density (B) behind the magnetizing force (H) or it is that quality of a magnetic substance due to which energy is dissipated in it on the reversal of its magnetism. The hysteresis loop equals the work which is necessary to reverse the direction of magnetization.

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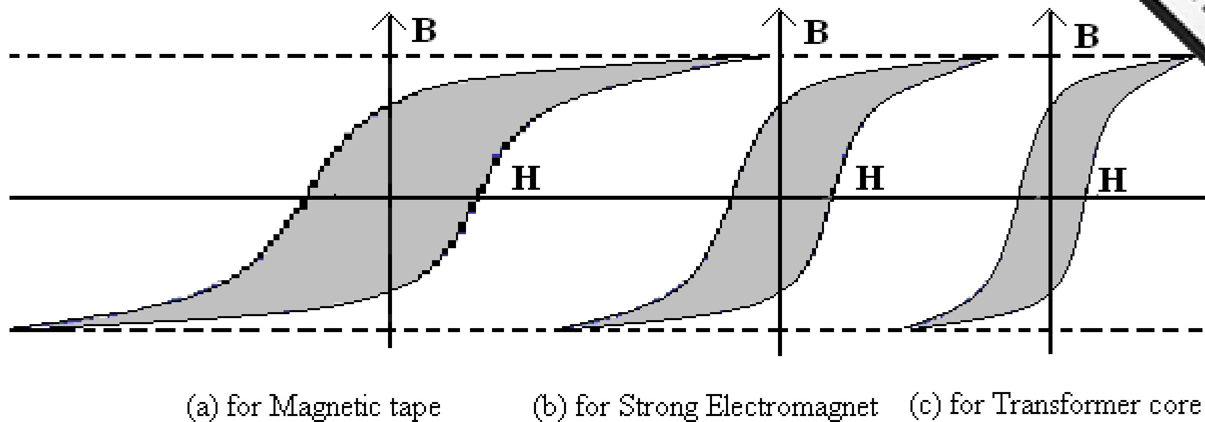

(a) for Magnetic tape (b) for Strong Electromagnet (c) for Transformer core

Q.48 Explain the phenomenon of polarization in dielectric materials. Name various types of polarizations and discuss their frequency dependence. **(7)**

Ans: Polarization in Dielectric Materials:

If a material contains polar molecules, they will generally be in random orientations when no electric field is applied. An applied electric field will polarize the material by orienting the dipole moments of polar molecules.

This decreases the effective electric field between the plates and will increase the capacitance of the parallel plate structure. The dielectric must be a good electric insulator so as to minimize any DC leakage current through a capacitor.

The various types of polarization processes are:

a) Electronic polarization
b) Ionic Polarization
c) Orientation Polarization, and
d) Space charge Polarization

Electronic Polarization is very rapid and occurs at all frequencies even in the optical range ($\sim 10^{15}$ Hz). Ionic Polarization is slower than electronic polarization and if an electric field of frequency in the optical range is now applied, the ions don't respond at all. So at optical frequencies there is no ionic polarization. Orientation Polarization is even slower than the ionic polarization and Orientation polarization occurs, when the frequency of the applied voltage is in the audio range. And the Space charge polarization occurs at machine frequencies only (50-60 Hz).

Q.49 Outline salient properties of Fermi probability function. Sketch it at two different temperatures. Define Fermi energy. What is its importance? **(7)**

Ans: At 0K, the free electrons occupy all the levels up to the Fermi level, leaving all those above it empty. At temperatures above 0K, due to thermal excitation, there is a finite probability of some of the electrons from below the Fermi level moving to levels above E_F.

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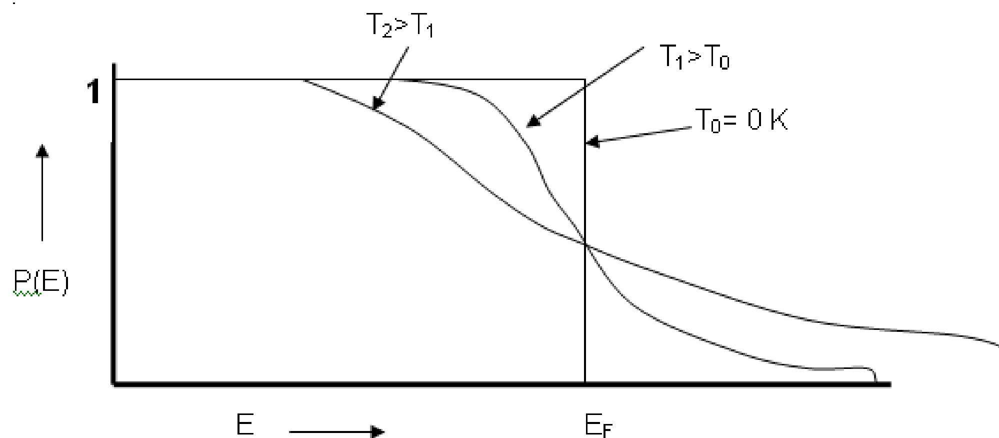
This probability is given by the Fermi-Dirac statistics, which takes into account the quan... restrictions due to the Pauli Exclusion Principle. The probability of occupation P (E) of a... energy level E by an electron is given by

$$P(E) = 1 / 1 + \exp[(E-E_F)/kT]$$

If E_F is independent of temperature, P (E) varies with E. At 0K, P (E) remains constant at unity with increasing E up to E_F, where it follows abruptly to zero. At T_1>0K, some of the electrons just below the Fermi level are thermally excited to higher levels just above E_F. So, P (E) is less than one just below the Fermi level and is greater than zero just above the Fermi level. At a still higher temperature, more electrons leave the lower energy levels and occupy higher levels. The cross-over point, where P (E) is 0.5 for different temperatures, occurs at the same value of the energy level which is E_F. This is true, provided that E_F is independent of temperature, an assumption valid for most ordinary temperatures. Under such conditions, the Fermi level can be defined as that level which has a 50% probability of occupation by an electron at any temperature.

The **Fermi energy** usually refers to the energy of the highest occupied quantum state in a system of fermions at absolute zero temperature. Thus Fermi Energy refers to the energy of the highest occupied state. What this means is that even if we have extracted all possible energy from a metal by cooling it down to near absolute zero temperature (0 Kelvin), the electrons in the metal are still moving around; the fastest ones would be moving at a velocity that corresponds to a kinetic energy equal to the Fermi energy.



Q.50 Discuss salient properties of common semiconducting materials. What are their uses? What are semiconducting devices? Where are they used? Give examples. **(7)**

Ans: The salient properties of semi-conducting materials are:

These are the materials whose valence electrons are bounded somewhat loosely to their atom.

They require energy less than dielectrics and more than good conductors to remove an electron from the parent atom.

They have:

(i) An empty conduction band

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(ii) Almost filled valance band

(iii) Very narrow energy gap (of about 1eV) separating the two bands.

Some of the commonly used semi-conducting materials are:

1) Germanium

Properties

- It is grey metallic looking lustrous material.
- It is brittle and glass like in its mechanical properties.
- It crystallizes in the diamond cubic lattice.

Uses

Germanium is widely used in making semi-conducting devices, rectifiers, photo conductive and photo voltaic cells, memory elements of computers etc.

2) Silicon

Properties

- It's a hard element having bluish-grey metallic lustre
- It has melting point of 1420ºC
- It is sensitive to impurities and radiations.

Uses

Silicon has become an important transistor material. It is used to make devices like Thyristors etc. Also it is used in computer memories. And it can be used in all the applications where germanium is used.

Semiconductor devices exploit the electronic properties of semiconductor materials, principally silicon, germanium, and gallium arsenide. Semiconductor devices have replaced thermionic devices (vacuum tubes) in most applications. They use electronic conduction in the solid state as opposed to the gaseous state or thermionic emission in a high vacuum.Semiconductor devices are manufactured both as discrete devices and as *integrated circuits* (ICs), which consist of a number—from a few to millions—of devices manufactured and interconnected on a single semiconductor substrate.Some of the semi conducting devices are diodes, transistors, thyristors, triac etc.

Semiconductor device applications

All transistor types can be used as the building blocks of logic gates, which are fundamental in the design of digital circuits. In digital circuits like microprocessors, transistors act as on-off switches; in the MOSFET, for instance, the voltage applied to the gate determines whether the switch is on or off.

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Transistors used for analog circuits do not act as on-off switches; rather, they respond to a continuous range of inputs with a continuous range of outputs. Common analog circuits include amplifiers and oscillators.

Circuits that interface or translate between digital circuits and analog circuits are known as mixed-signal circuits.

Power semiconductor devices are discrete devices or integrated circuits intended for high current or high voltage applications. Power integrated circuits combine IC technology with power semiconductor technology; these are sometimes referred to as "smart" power devices.

Q.51 State and explain Hall Effect? What are its applications? **(7)**

Ans: The **Hall Effect** refers to the potential difference (**Hall voltage**) on the opposite sides of an electrical conductor including semiconductors through which an electric current is flowing, created by a magnetic field applied perpendicular to the current.

The ratio of the voltage created to the product of the current and the magnetic field (I*B) divided by the element thickness, is known as the Hall coefficient. It is a characteristic of the material from which the conductor is made, as its value depends on the type, number and properties of the charge carriers that constitute the current.

The Hall Effect comes about due to the nature of the current flow in a conductor. Current consists of the movement of many small charge-carrying "particles" (typically, but not necessarily, electrons). Moving charges experience a force, called the Lorentz Force, when a magnetic field is present that is not parallel to their motion. When such a magnetic field is absent, the charges follow an approximately straight, 'line of sight' path. However, when a perpendicular magnetic field is applied, their path is curved so that moving charges accumulate on one face of the material. This leaves equal and opposite charges exposed on the other face, where there is a scarcity of mobile charges. The result is an asymmetric distribution of charge density across the Hall element that is perpendicular to both the 'line of sight' path and the applied magnetic field. The separation of charge establishes an electric field that opposes the migration of further charge, so a steady electrical potential builds up for as long as the current is flowing.

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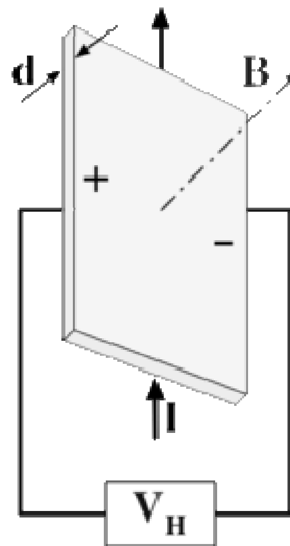

For a simple metal where there is only one type of charge carrier (electrons) the Hall voltage V_H is given by

$$V_H = \frac{-IB/d}{ne}.$$

The Hall coefficient is defined as

$$R_H = \frac{E_y}{j_x B} = \frac{V_H}{IB/d} = -\frac{1}{ne},$$

Where I is the current across the plate length, *B* is the magnetic flux density, *d* is the depth of the plate, *e* is the electron charge, and *n* is the charge carrier density of electrons. As a result, the Hall Effect is very useful as a means to measure both the carrier density and the magnetic field.

USES

Sensors and devices based on Hall Effect are used for:

1 Analog multiplication

2 Current sensing

3 Position and motion sensing

4 Automotive ignition and fuel injection

5 Wheel rotation sensing

6 Electric motor control

7 Industrial applications

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Q.52 Discuss the metallurgical factors which affect the quality of a welded joint. Explain soldering and brazing processes. **(7)**

Ans: The quality of a weld is dependent on the combination of materials used for the base material and the filler material. Not all metals are suitable for welding, and not all filler metals work well with acceptable base materials. Most often, the major metric used for judging the quality of a weld is its strength and the strength of the material around it. Many distinct factors influence this, including the welding method, the amount and concentration of energy input, the base material, the filler material, the flux material, the design of the joint, and the interactions between all these factors.

Soldering is a process in which two or more metal items are joined together by melting and flowing a filler metal into the joint, the filler metal having a relatively low melting point. Soft soldering is characterized by the melting point of the filler metal, which is below 400 °C (800 °F).The filler metal used in the process is called solder. Soldering is distinguished from brazing by use of a lower melting-temperature filler metal; it is distinguished from welding by the base metals not being melted during the joining process. In a soldering process, heat is applied to the parts to be joined, causing the solder to melt and be drawn into the joint by capillary action and to bond to the materials to be joined by wetting action. After the metal cools, the resulting joints are not as strong as the base metal, but have adequate strength, electrical conductivity, and water-tightness for many uses.

Brazing is a joining process whereby a filler metal or alloy is heated to melting temperature above 450 °C and is distributed between two or more close-fitting parts by capillary action. At its liquid temperature, the molten filler metal and flux interacts with a thin layer of the base metal, cooling to form a strong, sealed joint. By definition the melting temperature of the braze alloy is lower (sometimes substantially) than the melting temperature of the materials being joined. The brazed joint becomes a sandwich of different layers, each metallurgically linked to the adjacent layers.

Q.53 Explain Casting, Forging and Rolling. Name two components of structures and machines generally made by each of these processes. **(7)**

Ans: Casting is a manufacturing process by which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solid casting is then ejected or broken out to complete the process. Casting may be used to form hot liquid metals or various materials that cold set after mixing of components (such as epoxies, concrete, plaster and clay). Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods.

Forging is the term for shaping metal by using localized compressive forces. Cold forging is done at room temperature or near room temperature. Hot forging is done at a high temperature, which makes metal easier to shape and less likely to fracture. Warm forging is done at intermediate temperature between room temperature and hot forging temperatures.

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Forged parts can range in weight from less than a kilogram to 170 metric tons. Forged p usually require further processing to achieve a finished part.

Rolling is a metal working process in which metal is deformed by passing it through rollers at a temperature below its recrystallization temperature. Rolling increases the yield strength and hardness of a metal by introducing defects into the metal's crystal structure. These defects prevent further slip and can reduce the grain size of the metal, resulting in Hall-Petch hardening. Rolling is most often used to decrease the thickness of plate and sheet metal.

Q.54 Write notes on :

(i) Eddy current losses.
(ii) Any one alloy of copper and aluminium.

(7 x 2)

Ans:

i) Eddy Current Losses The core of a generator armature is made from soft iron, which is a conducting material with desirable magnetic characteristics. Any conductor will have currents induced in it when it is rotated in a magnetic field. These currents that are induced in the generator armature core are called EDDY CURRENTS. The power dissipated in the form of heat, as a result of the eddy currents, is considered a loss. Eddy currents, just like any other electrical currents, are affected by the resistance of the material in which the currents flow. And the resistance of any material is inversely proportional to its cross-sectional area.

(ii)Aluminum-Copper Alloys that contain 4 to 5% Cu, with the usual impurities of iron and silicon and sometimes with small amounts of magnesium, are heat-treatable and can reach quite high strength and ductility, especially if prepared from ingot containing less than 0.15% iron. Manganese in small amounts also may be added, mainly to combine with the iron and silicon and reduce their embrittling effect. However, these alloys have poor castability and require very careful gating if sound castings are to be obtained. Such alloys are used mainly in sand casting; when they are cast in metal molds, silicon must be added to increase fluidity and curtail hot shortness, and this addition of silicon substantially reduces ductility. AI-Cu alloys with somewhat higher copper contents (7 to 8%), formerly the most commonly used aluminum casting alloys, have steadily been replaced by AI-Cu-Si alloys and today are used to a very limited extent. The best attribute of these higher-copper Al-Cu alloys is their insensitivity to impurities, but they have very low strength and only fair castability. Also in limited use are AI-Cu alloys that contain 9 to 11 % Cu, whose high-temperature strength and wear resistance make them suitable for automotive pistons and cylinder blocks. These alloys usually contain manganese as an impurity because wrought metal scrap is used in preparing them. The manganese has little effect. Very good high-temperature strength is an attribute of alloys containing copper, nickel and magnesium, sometimes with iron in place of part of the nickel.

Q.55 Explain with suitable examples the ionic, covalent and metallic type of bondings in solids.

(9)

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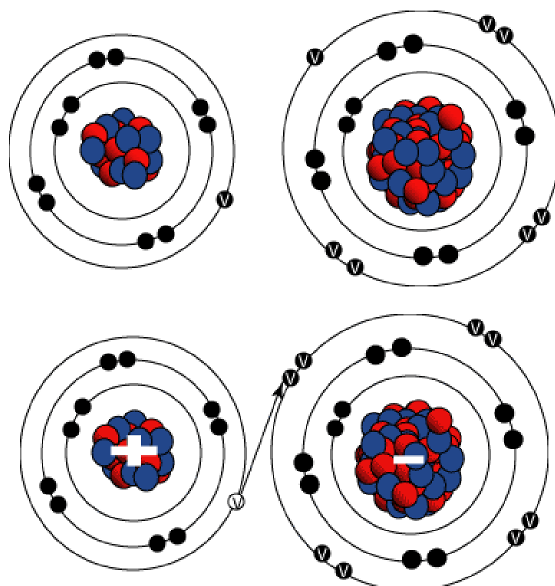
Ans: An ionic bond (or electrovalent bond) is a type of chemical bond that can often f between metal and non-metal ions (or polyatomic ions such as ammonium) throug electrostatic attraction. Or we can say, it is a bond formed by the attraction between two oppositely charged ions.



For example, common table salt is sodium chloride. When sodium (Na) and chlorine (Cl) are combined, the sodium atoms each lose an electron, forming a cation (Na+), and the chlorine atoms each gain an electron to form an anion (Cl-). These ions are then attracted to each other in a 1:1 ratio to form sodium chloride (NaCl).

A covalent bond is a form of chemical bonding that is characterized by the sharing of pairs of electrons between atoms, or between atoms and other covalent bonds. Or we can say that, attraction-to-repulsion stability that forms between atoms when they share electrons is known as covalent bonding.

Covalent bonding includes many kinds of interactions, including σ-bonding, π-bonding, metal-metal bonding, agostic interactions, and three-center two-electron bonds.

For example, in the molecule H_2, the hydrogen atoms share the two electrons via covalent bonding.

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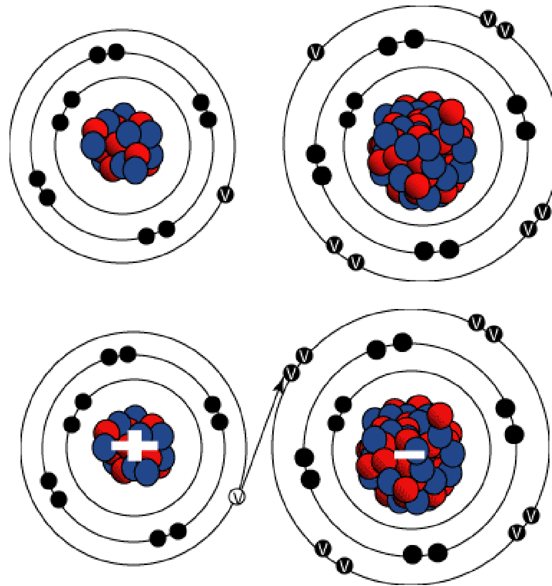

Metallic bonding is the electromagnetic interaction between delocalized electrons, called conduction electrons, and the metallic nuclei within metals. In the metallic bond, an atom achieves a more stable configuration by sharing the electrons in its outer shell with many other atoms. Metallic bonds prevail in elements in which the valence electrons are not tightly bound with the nucleus, namely metals, thus the name metallic bonding. In this type of bond, each atom in a metal crystal contributes all the electrons in its valence shell to all other atoms in the crystal. This free electron imparts electrical conductivity to metals.

For example, metallic bonding is found in metals like zinc.

Q.56 What are ferrites? Given an account of the applications of ferrites for high frequency transformers and computer memory cores, pointing out their advantages over a ferromagnetic material. **(2+6)**

Ans: Ferrites are usually non-conductive ferrimagnetic ceramic compounds derived from iron oxides such as hematite (Fe_2O_3) or magnetite (Fe_3O_4) as well as oxides of other metals. Ferrites are, like most other ceramics, hard and brittle. In terms of the magnetic properties, ferrites are often classified as "soft" and "hard" which refers to their low or high coercivity of their magnetism, respectively.

Ferrite cores are used in electronic inductors, transformers, and electromagnets where the high electrical resistance of the ferrite leads to very low eddy current losses. They are commonly seen as a lump in a computer cable, called a ferrite bead, which helps to prevent high frequency electrical noise (radio frequency interference) from exiting or entering the equipment.

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Early computer memories stored data in the residual magnetic fields of hard ferrite co[illegible] which were assembled into arrays of core memory. Ferrite powders are used in the coatings o[illegible] magnetic recording tapes. One such type of material is iron (III) oxide.

Ferrites have higher resistance than the ferromagnetic material. This makes them suitable for application at high frequencies- even microwave frequencies.

Q.57 Explain the principle of phase diagram. Discuss some simple binary phase diagrams. What are eutectic systems? **(9)**

Ans: A phase diagram is a type of graph used to show the equilibrium conditions between the thermodynamically-distinct phases. These can be single phase or Binary phase diagram.

Other much more complex types of phase diagrams can be constructed, particularly when more than one pure component are present. In that case concentration becomes an important variable. Phase diagrams with more than two dimensions can be constructed that show the effect of more than two variables on the phase of a substance. Phase diagrams can use other variables in addition to or in place of temperature, pressure and composition, for example the strength of an applied electric or magnetic field and they can also involve substances that take on more than just three states of matter.

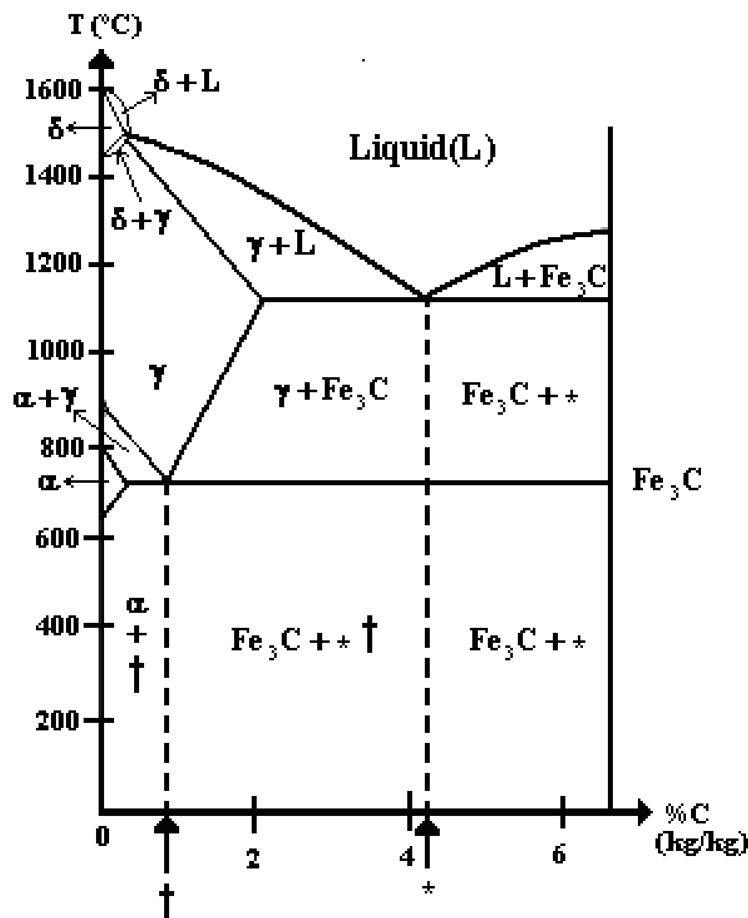

Fig: Iron–Iron Carbide (Fe–Fe_3C) phase diagram.

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The percentage of carbon present and the temperature define the phase of the iron carbon a and therefore its physical characteristics and mechanical properties. The percentage of carbo determines the type of the ferrous alloy: iron, steel or cast iron

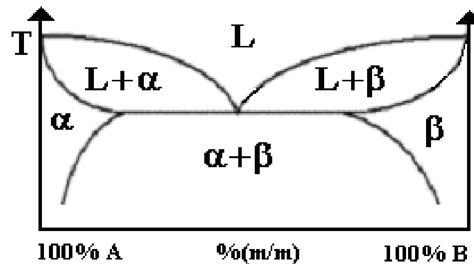


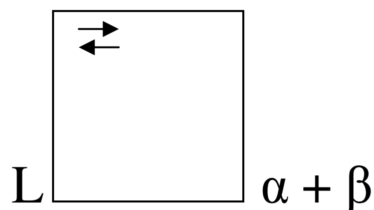
Fig: Phase diagram for a binary system displaying a eutectic point.

One type of phase diagram plots temperature against the relative concentrations of two substances in a binary mixture called a binary phase diagram, as shown above. Such a mixture can be a solid solution, eutectic or peritectic, among others. These two types of mixtures result in very different graphs. An example of a eutectic phase diagram is that of the olivine (forsterite and fayalite) system.A complex phase diagram of great technological importance is that of the iron-carbon system for less than 7% carbon.

The x-axis of such a diagram represents the concentration variable of the mixture. As the mixtures are typically far from being dilute and their density as a function of temperature usually unknown, the preferred concentration measure is mole fraction. A volume based measure like molarity would be unadvisable.

EUTECTIC SYSTEMS

An eutectic mixture is a mixture at such proportions that the melting point is as low as possible, and that furthermore all the constituents crystallize simultaneously at this temperature from molten liquid solution. Such a simultaneous crystallization of a eutectic mixture is known as a eutectic reaction, the temperature at which it takes place is the eutectic temperature, and the composition and temperature at which it takes place is called the eutectic point.



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In an equilibrium phase diagram for a binary system, the eutectic point is the point at wh
the liquid phase borders directly on the solid phase.

Q.58 What points should be considered for the selection of a good dielectric material? Discuss the application of PVC and mica in the manufacturing of electronic components. **(9)**

Ans: A dielectric material is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic field.

In practice, most dielectric materials are solid. Examples include porcelain (ceramic), mica, glass, plastics, and the oxides of various metals. Some liquids and gases can serve as good dielectric materials. Dry air is an excellent dielectric, and is used in variable capacitors and some types of transmission lines. Distilled water is a fair dielectric. A vacuum is an exceptionally efficient dielectric.

An important property of a dielectric is its ability to support an electrostatic field while dissipating minimal energy in the form of heat. The lower the dielectric loss (the proportion of energy lost as heat), the more effective is a dielectric material. Another consideration is the dielectric constant, the extent to which a substance concentrates on the electrostatic lines of flux. Substances with a low dielectric constant include a perfect vacuum, dry air, and pure, dry gases such as helium and nitrogen. Materials with moderate dielectric constants include ceramics, distilled water, paper, mica, polyethylene, and glass. Metal oxides, in general, have high dielectric constants.

Mica has a high dielectric strength and excellent chemical stability, making it a favoured material for manufacturing capacitors for radio frequency applications. It has also been used as an insulator in high voltage electrical equipment. It is also birefringent and is commonly used to make quarter and half wave plates.

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PVC is finding increased use as a composite dielectric for the production of accessorie... housings for portable electronics. Through a fusing process, it can adopt cleaning propertie... possessed by materials such as wool or cotton which can absorb dust particles and bacteria. Its inherent ability to absorb particles from the LCD screen and its form fitting characteristics make it effective

Q.59 Differentiate dielectric strength and dielectric breakdown. **(5)**

Ans: dielectric strength has the following meanings:

- Of an insulating material, the maximum electric field strength that it can withstand intrinsically without breaking down, *i.e.*, without experiencing failure of its insulating properties.
- For a given configuration of dielectric material and electrodes, the minimum electric field that produces breakdown.

The theoretical dielectric strength of a material is an intrinsic property of the bulk material and is dependent on the configuration of the material or the electrodes with which the field is applied.

Q.60 Discuss different methods of soldering. (6)

Ans: DIFFERENT SOLDERING METHODS

Soldering methods are broadly divided into two types: the partial heating method and the total heating method. In Partial heating method, heat is applied to the package leads and/or PWB in a localized manner.

There are two types of soldering methods:
1) Soldering iron
2) Hot air

(1) Soldering with soldering iron
This method consists of using a soldering iron to solder the package leads and printed circuit with wire solder, etc.
Determine the soldering temperature of the soldering iron to be used according to the size and shape of the location to be soldered, and the melting point of the solder.

If the soldering temperature is too high, the printed circuit may peel off from PWB and various degradation may be caused due to overheating.

The actual soldering temperature must be determined according to the thermal capacity of the SMD. It is actually recommended that the temperature characteristics of the SMD be actually

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measured to determine the soldering temperature. Whenever possible, use a soldering iron whose temperature can be adjusted.

(2) Hot air soldering
This method solders the SMD by heating air or N2 gas with a heater and flowing hot gas from a nozzle onto the joint on the PWB. The temperature is adjusted by adjusting the heat source and/or the flow of gas.
Partial heating involves less heat stress on the device and wiring board, but is unsuitable for large volume production.
Therefore, this method is mainly used to correct soldering or for devices with a low heat resistance.

In Total heating method, heat is applied to the entire package and/or PWB.
There are five types of such soldering methods:
1) Infrared reflow
2) Convection reflow
3) Infrared convection combined
4) VPS (Vapour Phase Soldering)
5) flow (wave) soldering

Because of excellence in productivity and running cost, these types are widely used. However, this method can place considerable heat stress on the semiconductor device and board.

Q.61 Give a quantitative explanation for the formation of energy bands in a solid. **(8)**

Ans: The electronic band structure (or simply band structure) of a solid describes ranges of energy that an electron is "forbidden" or "allowed" to have. It is due to the diffraction of the quantum mechanical electron waves in the periodic crystal lattice. The band structure of a material determines several characteristics, in particular its electronic and optical properties.

Any solid has a large number of bands. In theory, it can be said to have infinitely many bands (just as an atom has infinitely many energy levels). However, all but a few lie at energies so high that any electron that reaches those energies escapes from the solid. These bands are usually disregarded.

Bands have different widths, based upon the properties of the atomic orbitals from which they arise. Also, allowed bands may overlap, producing (for practical purposes) a single large band.

Metals contain a band that is partly empty and partly filled regardless of temperature. Therefore they have very high conductivity.

The lowermost, almost fully occupied band in an *insulator* or *semiconductor* is called the *valence band* by analogy with the valence electrons of individual atoms. The uppermost,

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almost unoccupied band is called the *conduction band* because only when electrons are excited to the conduction band can current flow in these materials. The difference between insulators and semiconductors is only that the forbidden band gap between the valence band and conduction band is larger in an insulator, so that fewer electrons are found there and the electrical conductivity is lower. Because one of the main mechanisms for electrons to be excited to the conduction band is due to thermal energy, the conductivity of semiconductors is strongly dependent on the temperature of the material.

This band gap is one of the most useful aspects of the band structure, as it strongly influences the electrical and optical properties of the material. Electrons can transfer from one band to the other by means of carrier generation and recombination processes. The band gap and defect states created in the band gap by doping can be used to create semiconductor devices such as solar cells, diodes, transistors, laser diodes, and others.

Q.62 Name two important properties of stainless steel as compared to carbon and alloy steel. What type of stainless steel would you prefer for household utensils? Why? **(8)**

Ans: Stainless steel is defined as a steel alloy with a minimum of 11.5% chromium content by mass. Stainless steel does not stain, corrode or rust as easily as ordinary steel (it is "stains less"). It is also called corrosion resistant steel when the alloy type and grade are not detailed, particularly in the aviation industry. There are different grades and surface finishes of stainless steel to suit the environment to which the material will be subjected in its lifetime. Common uses of stainless steel are cutlery and watch straps.

Stainless steel differs from carbon steel by amount of chromium present. Carbon steel rusts when exposed to air and moisture. This iron oxide film is active and accelerates corrosion by forming more iron oxide. Stainless steels have sufficient amount of chromium present so that a passive film of chromium oxide forms which prevents further corrosion.

The stainless steel can be classified as:-

- Austenitic: Chromium-nickel-iron alloys with 16-26% chromium, 6-22% nickel (Ni), and low carbon content, with non-magnetic properties (if annealed - working it at low temperatures, then heated and cooled). Nickel increases corrosion resistance. Hardenable by cold-working (worked at low temperatures) as well as tempering (heated then cooled). Type 304 (S30400) or "18/8" (18% chromium 8% nickel), is the most commonly used grade or composition.
- Martensitic: Chromium-iron alloys with 10.5-17% chromium and carefully controlled carbon content, hardenable by quenching (quickly cooled in water or oil) and tempering (heated then cooled). It has magnetic properties. Commonly used in knives. Martensitic grades are strong and hard, but are brittle and difficult to form and weld. Type 420 (S42000) is a typical example.
- Ferritic: Chromium-iron alloys with 17-27% chromium and low carbon content, with magnetic properties. Cooking utensils made of this type contain the higher chromium levels. Type 430 is the most commonly used ferritic.

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All of these have following applications:
The austenitic microstructure is most commonly used for knives and cooking utensils. It is very tough, hardened through a process that consists of heating, cooling and heating. It resists scaling and retains strength at high temperatures.
Both ferritics and austenitics are used in kitchenware and household appliances. Austenitics are preferred in the food industry and beverage equipment due to the superior corrosion resistance and ease of cleaning. Type 301, for example, is an austenitic stainless steel, with 17% chromium, 7% nickel, and .05% carbon, and is widely used for institutional food preparation utensils.

Low quality cutlery is generally made out of grades like 409 and 430 (ferritic), while the finest Sheffield cutlery uses specially produced 410 and 420 (martensitic) for the knives, and 304 (austenitic) for the spoons and forks. Grades like the 410/420 can be hardened and tempered so that the knife blades will take a sharp edge, whereas the more ductile 304 stainless is easier to work with and therefore more suitable for objects that have to undergo numerous shaping, buffing and grinding processes.
The best quality stainless steel knife blades have high carbon content, and usually have molybdenum and vanadium in their composition.

Q.63 Differentiate between chemical vapour deposition and lithography. **(6)**

Ans: Chemical vapor deposition (CVD) is a chemical process used to produce high-purity, high-performance solid materials. The process is often used in the semiconductor industry to produce thin films. In a typical CVD process, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit. Frequently, volatile by-products are also produced, which are removed by gas flow through the reaction chamber.

Whereas Photolithography, which is one of the kinds of lithography is a process used in microfabrication to selectively remove parts of a thin film (or the bulk of a substrate). It uses light to transfer a geometric pattern from a photomask to a light-sensitive chemical (photoresist), on the substrate. A series of chemical treatments then engraves the exposure pattern into the material underneath the photoresist. In a complex integrated circuit (for example, modern CMOS), a wafer will go through the photolithographic cycle up to 50 times.

Q.64 What is the meaning of "holding or soaking" time in heat treatment processes? How does it affect the properties of steel? **(7)**

Ans: Holding or Soaking time can be defined as the time for which prolonged heating of a metal is done at a selected temperature.

Soaking at a lower solution temperature, however, requires longer holding times to achieve adequate solution treatment within the alloy. A higher soaking temperature allows one to shorten the total holding time while still achieving adequate solution treatment within the alloy.

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Q.65 What is major difference in the purpose of annealing and normalizing? **(7)**

Ans: ANNEALING AND NORMALIZING:-

When steel is heated to a point 50^0-75^0 above its critical range, a condition referred to as "austenite" is produced. If slowly cooled from above its critical temperature, the austenite is broken down and a succession of other conditions are produced, each being normal for a particular range of temperatures. Starting with austenite, these successive conditions are martensite, troostite, sorbite, and finally pearlite. The most important step in annealing is to raise the temperature of the metal above the critical point, as any hardness that may have existed will then be completely removed. Strains that may have been set up through heat treatment will be eliminated when the steel is heated to the critical point, and then restored to its lowest hardness by slow cooling. In annealing, the steel must never be heated more than approximately 28° to 40°C above the critical point. When large articles are annealed, sufficient time must be allowed for the heat to penetrate the metal.
Steel is usually subjected to the annealing process for the following purposes:

1. To increase its ductility by reducing hardness and brittleness.
2. To refine the crystalline structure and remove residual stresses.

Steel that has been cold worked is usually annealed to increase its ductility. Assuming that the part to be annealed is heated to the proper temperature, the required slow cooling may be accomplished in several ways, depending on the metal and the degree of softness required. Normalizing, although involving a slightly different heat treatment, may be classified as a form of annealing. This process removes all strains due to machining, forging, bending and welding. Normalizing can only be accomplished with a good furnace, where the temperatures and the atmosphere may be closely regulated and held constant throughout the entire operation. . A reducing atmosphere will normalize the metal with a minimum amount of oxide scale, while an oxidizing atmosphere will leave the metal heavily coated with scale, thus preventing proper development of hardness in any subsequent hardening operation. The articles are put in the furnace and heated to a point above the critical temperature of the steel. After the parts have been held at this temperature for a sufficient time to allow the heat to penetrate to the centre of the section, they must be removed from the furnace and cooled in still air. Drafts will result in uneven cooling, which will again set up strains in the metal. Prolonged soaking of the metal at high temperatures must be avoided, as this practice will cause the grain structure to enlarge. The length of time required for the soaking temperature will depend upon the mass of metal being treated.

The main difference between annealing and normalizing is that annealed parts are uniform in softness (and machinablilty) throughout the entire part since the entire part is exposed to the controlled furnace cooling. In the case of the normalized part, depending on the part geometry, the cooling is non-uniform resulting in non-uniform material properties across the part. This may not be desirable if further machining is desired, since it makes the machining job somewhat unpredictable. In such a case it is better to do full annealing.

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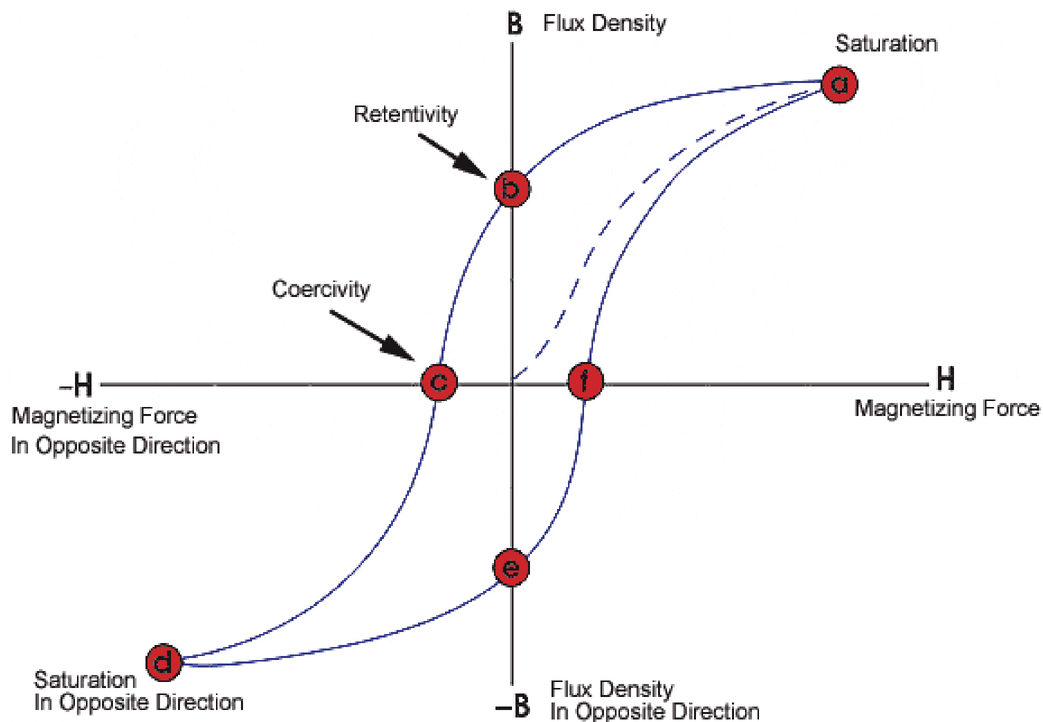
Q.66 Write notes on any TWO of the following :
(i) Domain theory of hysteresis.
(ii) Role of manganese in cast irons.
(iii) Rolling

(7 x 2)

Ans: (i) A great deal of information can be learned about the magnetic properties of a material by studying its hysteresis loop. A hysteresis loop shows the relationship between the induced magnetic flux density (B) and the magnetizing force (H). It is often referred to as the B-H loop. An example hysteresis loop is shown below.



The loop is generated by measuring the magnetic flux of a ferromagnetic material while the magnetizing force is changed. A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as H is increased. As the line demonstrates, the greater the amount of current applied (H+), the stronger the magnetic field in the component (B+). At point "a" almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux. The material has reached the point of magnetic saturation. When H is reduced to zero, the curve will move from point "a" to point "b." At this point, it can be seen that some magnetic flux remains in the material even though the magnetizing force is zero. This is referred to as the point of retentivity on the graph and indicates the remanence or level of residual magnetism in the material. (Some of the magnetic domains remain aligned but some have lost their alignment.) As the magnetizing force is reversed, the curve moves to point "c", where the flux has been reduced to zero.

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This is called the point of coercivity on the curve. (The reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero.) The force required to remove the residual magnetism from the material is called the coercive force or coercivity of the material. As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction (point "d"). Reducing H to zero brings the curve to point "e." It will have a level of residual magnetism equal to that achieved in the other direction. Increasing H back in the positive direction will return B to zero. Notice that the curve did not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path from point "f" back to the saturation point where it with complete the loop.

(ii) Role of Manganese in Cast Iron

- Stabilising austenite
- Acts as deoxidizer
- Refines the graphite and pearlite
- Refines the grains
- Increases the basic mechanical properties when added in low percentage.

(iii) Rolling process is the easiest way of reducing the cross-sectional area of a piece of material to have uniform and long lengths of the product. Most of the steel-building materials are produced by this process. Rolling can be classified as Hot Rolling and Cold Rolling.

Cold rolling is a metal working process in which metal is deformed by passing it through rollers at a temperature below its recrystallization temperature. Cold rolling increases the yield strength and hardness of a metal by introducing defects into the metal's crystal structure. These defects prevent further slip and can reduce the grain size of the metal, resulting in Hall-Petch hardening. Cold rolling is most often used to decrease the thickness of plate and sheet metal.

Hot rolling, also called hot working, is a metallurgical process in which large pieces of metal such as slabs or billets are deformed between roller at high temperature to form thinner cross sections. Hot rolling produces thinner cross sections than cold rolling processes with the same number of stages. Hot rolling will reduce the average grain size of a metal while maintaining an equiaxed microstructure where as cold rolling will produce a hardened microstructure

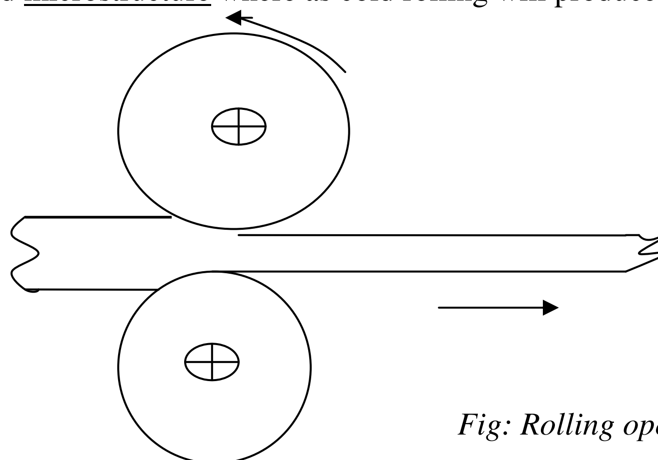

Fig: Rolling operation with two rollers.

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Q.67 Differentiate between the following:
(i) Extrinsic and intrinsic properties.
(ii) Phase and component. **(3.5 x 2)**

Ans: (i) A pure semiconductor is called intrinsic semiconductor and it has properties that of an insulator. There are no free electrons available since all the co-valent bonds are complete. Here the no. of electrons and holes are equal thus conductivity is poor. And the resistance decreases with increase in temperature. But when tetravalent or Pentavalent impurity is added to an intrinsic semiconductor it results into an extrinsic semiconductor. On adding impurity it attains the current conducting properties. Here the no. of electrons is not equal to that of holes and so has better conductivity. Their conductivity increases with increase in temperature.

(ii) A Phase is a physically distinct, chemically homogenous and mechanically separable region of a system. The various states of aggregation of matter, namely, the gaseous, the liquid and the solid states, form separate phases. Whereas the Components of a system may be elements, ions or compounds. They refer to the independent chemical species that comprise the system.

Q.68 Distinguish between ionic and metallic-bonds in solids? **(7)**

Ans: Ionic bond exists due to electrostatic force of attraction between positive and negative ions of different elements whereas Metallic bonds exist due to electrostatic force of attraction between the electron cloud of valence electrons and positive ions of the same or different metal.

Ionic bonds have low thermal conductivity whereas metallic bonds have good thermal conductivity.

Ionic bonds are generally stronger than the metallic bonds.

Solids formed with ionic bonding have high hardness whereas solids formed with metallic bonding have high ductility.

Q.69 Explain the following terms as applied to crystals:
(i) Crystal lattice. (ii) Unit cell.
(iii) Lattice parameters of a unit cell (iv) Primitive cell
(v) Packing Factor. (vi) Atomic radius.
(vii) Co-ordination number. **(7)**

Ans: (i) Crystal Lattice

It can be defined as the orderly, regular three-dimensional arrangement of atoms in a crystal. Also it can be considered as an infinite periodic array of points.

Example: NaCl crystal lattice structure

(ii) Unit cell

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The unit cell is the basic building block of a crystal, repeated infinitely in three dimension is characterised by the three vectors (*a, b, c*) that form the edges of a parallelepiped and th angles between the vectors (*alpha*, the angle between *b* and *c*; *beta*, the angle between *a* and *c; gamma*, the angle between *a* and *b*).

(iii) Lattice parameters of a Unit cell

The size of the unit-cell is described in terms of its unit-cell parameters. The set of six numbers are called the lattice parameters. These are the edge lengths of the unit cell i.e. a, b and c respectively and the angles of the unit-cell (*alpha*, the angle between *b* and *c*; *beta*, the angle between *a* and *c; gamma*, the angle between *a* and *b*).

(iv) Primitive cell

A primitive cell is a unit cell built on the basis vectors of a primitive basis of the direct lattice, namely a crystallographic basis of the vector lattice **L** such that every lattice vector **t** of **L** may be obtained as an integral linear combination of the basis vectors, **a**, **b**, **c**. It contains only one lattice point and its volume is equal to the triple scalar product (**a**, **b**, **c**).

Non-primitive bases are used conventionally to describe *centred lattices*. In that case, the unit cell is a multiple cell and it contains more than one lattice point. The multiplicity of the cell is given by the ratio of its volume to the volume of a primitive cell.

(v) Packing factor

Atomic packing factor (APF) or **packing fraction** is the fraction of volume in a crystal structure that is occupied by atoms. It is dimensionless and always less than unity. For practical purposes, the APF of a crystal structure is determined by assuming that atoms are rigid spheres. For one-component crystals (those that contain only one type of atom), the APF is represented mathematically by

$$\mathrm{APF} = \frac{N_{\mathrm{atoms}} V_{\mathrm{atom}}}{V_{\mathrm{crystal}}}$$

Where N_{atoms} is the number of atoms in the crystal, V_{atom} is the volume of an atom, and $V_{crystal}$ is the volume occupied by the crystal. It can be proven mathematically that for one-component structures, the densest arrangement of atoms has an APF of about 0.74. In reality, this number can be higher due to specific intermolecular factors. For multiple-component structures, the APF can exceed 0.74.

(vi) Atomic Radius

Atomic radius is defined as half the distance between nearest neighbours in a crystal of a pure element.

(vii) Co-ordination number

The **coordination number** of an atom in a molecule or a crystal is the number of its nearest neighbours. This number is determined somewhat differently for molecules and for crystals.

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Q.70 What are the metallurgical factors which affect the quality of a welded joint? **(2)**

Ans: The **quality of a weld** is dependent on the combination of materials used for the base material and the filler material. Not all metals are suitable for welding, and not all filler metals work well with acceptable base materials. Most often, the major criterion used for judging the quality of a weld is its strength and the strength of the material around it. Many distinct factors influence this, including the welding method, the amount and concentration of energy input, the base material, the filler material, the flux material, the design of the joint, and the interactions between all these factors.

Q.71 Compare the mechanical properties and uses of mild steel, tool steels and alloy steels. **(9)**

Ans: Mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel has low carbon content (up to 0.3%) and is therefore neither extremely brittle nor ductile. It becomes malleable when heated, and so can be forged. It is also often used where large amounts of steel need to be formed, for example as structural steel. Density of this metal is 7,861.093 kg/m^3 (0.284 lb/in^3), the tensile strength is a maximum of 500 MPa (72,500 psi) and it has a Young's modulus of 210 GPa.

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures (red-hardness).

With carbon content between 0.7% and 1.4%, tool steels are manufactured under carefully controlled conditions to produce the required quality. The manganese content is often kept low to minimise the possibility of cracking during water quenching. However, proper heat treating of these steels is important for adequate performance, and there are many suppliers who provide tooling blanks intended for oil quenching.

Tool steels are made to a number of grades for different applications. Choice of grade depends on, among other things, whether a keen cutting edge is necessary, as in stamping dies, or whether the tool has to withstand impact loading and service conditions encountered with such hand tools as axes, pickaxes, and quarrying implements. In general, the edge temperature under expected use is an important determinant of both composition and required heat treatment. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools, etc.

Tool steels are also used for special applications like injection molding, because the resistance to abrasion is an important criterion for a mold that will be used to produce hundreds of thousands of parts.

Low-alloy Steels:

When these steels are designed for welded applications, their carbon content is usually below 0.25 percent and often below 0.15 percent. Typical alloys include nickel, chromium,

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molybdenum, manganese, and silicon, which add strength at room temperatures and incr... low-temperature notch toughness.

These alloys can, in the right combination, improve corrosion resistance and influence the steel's response to heat treatment. But the alloys added can also negatively influence crack susceptibility, so it's a good idea to use low-hydrogen welding processes with them. Preheating might also prove necessary.

High-alloy Steels:

For the most part, we are talking about stainless steel here, the most important commercial high-alloy steel. Stainless steels are at least 12 percent chromium and many have high nickel contents. The three basic types of stainless are:

1. Austenitic
2. Ferritic
3. Martensitic

Martensitic stainless steels make up the cutlery grades. They have the least amount of chromium, offer high hardenability, and require both pre- and post heating while welding to prevent cracking in the heat-affected zone (HAZ).

Ferritic stainless steels have 12 to 27 percent chromium with small amounts of austenite-forming alloys.

Austenitic stainless steels offer excellent weldability, but austenite isn't stable at room temperature. Consequently, specific alloys must be added to stabilize austenite. The most important austenite stabilizer is nickel, and others include carbon, manganese, and nitrogen.

Special properties, including corrosion resistance, oxidation resistance, and strength at high temperatures, can be incorporated into austenitic stainless steels by adding certain alloys like chromium, nickel, molybdenum, nitrogen, titanium, and columbium. While carbon can add strength at high temperatures, it can also reduce corrosion resistance by forming a compound with chromium. It's important to note that austenitic alloys can't be hardened by heat treatment. That means they don't harden in the welding HAZ.

Q.72 Write short note on Lithography and its applications. **(5)**

Ans: The word **lithography** comes from the Greek lithos, meaning stones, and graphia, meaning to write. It means quite literally writing on stones. In the case of semiconductor lithography our stones are silicon wafers and our patterns are written with a light sensitive polymer called a photoresist. To build the complex structures that make up a transistor and the many wires that connect the millions of transistors of a circuit, lithography and etch pattern transfer steps are repeated at least 10 times, but more typically are done 20 to 30 times to make one circuit. Each pattern being printed on the wafer is aligned to the previously formed patterns and slowly the conductors, insulators, and selectively doped regions are built up to fabricate the final device.

Q.73 Differentiate between welding, soldering, and brazing processes. **(7)**

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Ans: Welding is a fabrication process that joins materials, usually metals, or thermoplastics, by causing coalescence. This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the weld puddle) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the workpieces to form a bond between them, without melting the workpieces.

Soldering is a process in which two or more metal items are joined together by melting and flowing a filler metal into the joint, the filler metal having a relatively low melting point. Soft soldering is characterized by the melting point of the filler metal, which is below 400 °C. The filler metal used in the process is called solder. Soldering is distinguished from brazing by use of a lower melting-temperature filler metal; it is distinguished from welding by the base metals not being melted during the joining process. In a soldering process, heat is applied to the parts to be joined, causing the solder to melt and be drawn into the joint by capillary action and to bond to the materials to be joined by wetting action. After the metal cools, the resulting joints are not as strong as the base metal, but have adequate strength, electrical conductivity, and water-tightness for many uses.

Brazing is a joining process whereby a filler metal or alloy is heated to melting temperature above 450 °C and distributed between two or more close-fitting parts by capillary action. At its liquid temperature, the molten filler metal and flux interacts with a thin layer of the base metal, cooling to form a strong, sealed joint. By definition the melting temperature of the braze alloy is lower (sometimes substantially) than the melting temperature of the materials being joined. The brazed joint becomes a sandwich of different layers, each metallurgically linked to the adjacent layers.

Q.74 Compare hot working and cold working processes. **(7)**

Ans: Cold and Hot working processes

Plastic deformation which is carried out in a temperature region and over a time interval such that the strain hardening is not relieved is called cold working. In the early stages of plastic deformation, slip is essentially on primary glide planes and the dislocations form coplanar arrays. As deformation proceeds, cross slip takes place. The cold-worked structure forms high dislocation density regions that soon develop into networks. The grain size decreases with strain at low deformation but soon reaches a fixed size.

Cold working will decrease ductility. Hot working refers to the process where metals are deformed above their recrystallization temperature and strain hardening does not occur. Hot working is usually performed at elevated temperatures. Lead, however, is hot-worked at room temperature because of its low melting temperature. At the other extreme, molybdenum is cold-worked when deformed even at red heat because of its high recrystallization temperature.

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The resistance of metals to plastic deformation generally falls with temperature. For reason, larger massive sections are always worked hot by forging, rolling, or extrusion. Meta display distinctly viscous characteristics at sufficiently high temperatures, and their resistance to flow increases at high forming rates. This occurs not only because it is a characteristic of viscous substances, but because the rate of recrystallization may not be fast enough.

Q.75 Discuss properties and applications of following
(i) Bakelite. (ii) Mica. **(7)**

Ans: (i) Properties of Bakelite

Bakelite is a material based on the thermosetting phenol formaldehyde resin. Formed by the reaction under heat and pressure of phenol (a toxic, colourless crystalline solid) and formaldehyde (a simple organic compound), generally with a wood flour filler, it was the first plastic made from synthetic components. It was used for its electrically nonconductive and heat-resistant properties in radio and telephone casings and electrical insulators, and was also used in such diverse products as kitchenware, jewellery, pipe stems, and children's toys.

Today, Bakelite is manufactured and produced in the form of sheets, rods and tubes for hundreds of industrial applications in the electronics, power generation and aerospace industries, and under a variety of commercial brand names, including Garolite.

Bakelite sheet is a hard, dense material made by applying heat and pressure to layers of paper or glass cloth impregnated with synthetic resin. These layers of laminations are usually of cellulose paper, cotton fabrics, synthetic yarn fabrics, glass fabrics or unwoven fabrics. When heat and pressure are applied to the layers, a chemical reaction (polymerization) transforms the layers into a high-pressure thermosetting industrial laminated plastic. When rubbed, original Bakelite has a telltale odor.

Applications and usage

Although not extensively used as an industrial manufacturing material any more, in the past Bakelite was used in myriad applications, such as saxophone mouthpieces, cameras, solid-body electric guitars, rotary-dial telephones, early machine guns, and appliance casings. It was at one point considered for the manufacture of coins, due to a shortage of traditional manufacturing material.

(ii) Properties and uses of MICA

Mica has a high dielectric strength and excellent chemical stability, making it a favoured material for manufacturing capacitors for radio frequency applications. It has also been used as an insulator in high voltage electrical equipment. It is also birefringent and is commonly used to make quarter and a half wave plates. Because mica is resistant to heat it is used instead of glass in windows for stoves and kerosene heaters. It is also used to separate electrical conductors in cables that are designed to have a fire-resistance rating in order to provide circuit integrity. The idea is to keep the metal conductors away from fusing in order to prevent a short-circuit so that the cables remain operational during a fire, which can be important for

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applications such as emergency lighting. Illites or clay micas have a low cation excha... capacity for 2:1 clays. K+ ions between layers of mica prevent swelling by blocking wate... molecules. Aventurine is a variety of quartz with mica inclusions used as a gemstone. Pressed Mica sheets are often used in place of glass in greenhouses. Muscovite mica is the most common substrate for sample preparation for the atomic force microscope. Some brands of toothpaste include powdered white mica. This acts as a mild abrasive to aid polishing of the tooth surface, and also adds a cosmetically-pleasing glittery shimmer to the paste. The shimmer from mica is also used in makeup, as it gives a translucent "glow" to the skin or helps to mask imperfections. Mica sheets are used to provide structure for heating wire (like Kanthal, Nichrome, etc.) in heating elements and can withstand up to 900 °C. Another use of Mica is in the production of ultra flat thin film surfaces (e.g. gold surfaces) using mica as substrate. Although the deposited film surface is still rough due to deposition kinetics, the back side of the film at mica-film interface provides ultra flatness, when the film is removed from the substrate. Mica slices are used in electronics to provide electric insulation between a heat generating component and the heat sink used to cool it.

Q.76 Give properties and uses of following materials
(i) Manganin (ii) Nichrome **(7)**

Ans:

(i) Manganin is a trademarked name for an alloy of typically 86% copper, 12% manganese, and 2% nickel. Manganin foil and wire is used in the manufacture of resistors, particularly ammeter shunts, because of its virtually zero temperature coefficient of resistance value and long term stability. Manganin wire is also used as an electrical conductor in cryogenic systems, minimizing heat transfer between points which need electrical connections. Manganin is also used in gauges for studies of high-pressure shock waves (such as those generated from the detonation of explosives) because it has low strain sensitivity but high hydrostatic pressure sensitivity.

(ii) Nichrome

Nichrome is a brand name for a nickel-chromium resistance wire, a non-magnetic alloy of nickel and chromium. A common alloy is 80% nickel and 20% chromium, but there are many others to accommodate various applications. It is silvery-grey in colour, is corrosion resistant, and has a high melting point of about 1400 °C. Due to its relatively high resistivity and resistance to oxidation at high temperatures, it is widely used in heating elements, such as in hair dryers, electric ovens and toasters. Typically, Nichrome is wound in wire coils to a certain electrical resistance, and current passed through to produce heat. Nichrome is used in the explosives and fireworks industry as a reliable ignition system, such as electric matches and model rocket igniters. The alloy tends to be expensive due to its high nickel content. Other areas of usage include motorcycle silencers, and in certain microbiological lab apparatus.

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Q.77 Briefly describe the process and purpose of the following heat treatment operations
(i) Full annealing. (ii) Hardening.
(iii) Tempering. **(9)**

Ans:

(i) Full Annealing

A full anneal typically results in the most ductile state a metal can assume for metal alloy. To perform a full anneal, a metal is heated to its annealing point (about 50°c above the austenic temperature) and held for sufficient time to allow the material to fully austenitize, to form austenite or austenite-cementite grain structure. The material is then allowed to cool slowly so that the equilibrium microstructure is obtained. In some cases this means the material is allowed to air cool. In other cases the material is allowed to furnace cool. The details of the process depend on the type of metal and the precise alloy involved. In any case the result is a more ductile material that has greater stretch ratio and reduction of area properties but a lower yield strength and a lower tensile strength. This process is also called LP annealing for *lamellar pearlite* in the steel industry as opposed to a *process anneal* which does not specify a microstructure and only has the goal of softening the material. Often material that is annealed will be machined and then be followed by further heat treatment to obtain the final desired properties.

(ii) Work hardening, **strain hardening**, or **cold work** is the strengthening of a material by increasing the material's dislocation density. In metallic crystals, irreversible deformation is usually carried out on a microscopic scale by defects called dislocations, which are created by fluctuations in local stress fields within the material culminating in a lattice rearrangement as the dislocations propagate through the lattice. At normal temperatures the dislocations are not annihilated by annealing. Instead, the dislocations accumulate, interact with one another, and serve as pinning points or obstacles that significantly impede their motion. This leads to an increase in the yield strength of the material and a subsequent decrease in ductility.

(iii) Tempering is a heat treatment technique for metals and alloys. In steels, tempering is done to "toughen" the metal by transforming brittle martensite into bainite or a combination of ferrite and cementite. Precipitation hardening alloys, like many grades of aluminum and super alloys, are tempered to precipitate intermetallic particles which strengthen the metal.

Q.78 Describe the process of extrusion giving its advantages. **(5)**

Ans: Extrusion is a process used to create objects of a fixed cross-sectional profile. A material is pushed or drawn through a die of the desired cross-section. The two main advantages of this process over other manufacturing processes is its ability to create very complex cross-sections and work materials that are brittle, because the material only encounters compressive and shear stresses. It also forms finished parts with an excellent surface finish.

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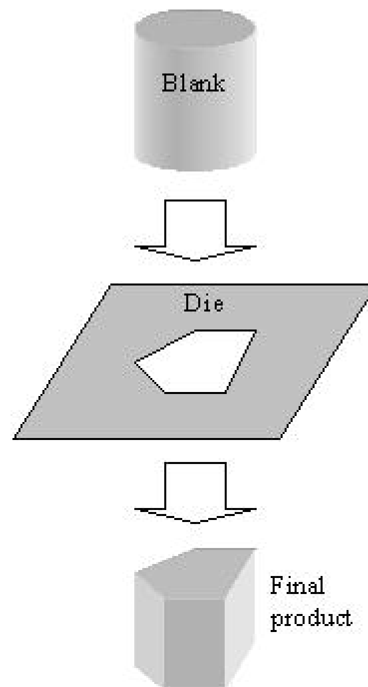
Extrusion may be continuous (theoretically producing indefinitely long material) or se continuous (producing many pieces). The extrusion process can be done with the material ho or cold. Commonly extruded materials include metals, polymers, ceramics, and foodstuffs.



Extrusion of a round blank through a die.

The process begins by heating the stock material. It is then loaded into the container in the press. A dummy block is placed behind it where the ram then presses on the material to push it out of the die. Afterwards the extrusion is stretched in order to straighten it. If better properties are required, then it may be heat treated or cold worked.

Hot extrusion

Hot extrusion is done at an elevated temperature to keep the material from work hardening and to make it easier to push the material through the die. Most hot extrusions are done on horizontal hydraulic presses that range from 250 to 12,000 tons. Pressures range from 5,000 to 100,000 psi, therefore lubrication is required, which can be oil or graphite for lower temperature extrusions, or glass powder for higher temperature extrusions. The biggest disadvantage of this process is its cost for machinery and its upkeep.

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Cold extrusion

Cold extrusion is done at room temperature or near room temperature. The advantages of this over hot extrusion are the lack of oxidation, higher strength due to cold working, closer tolerances, good surface finish, and fast extrusion speeds if the material is subject to hot shortness.

Materials that are commonly cold extruded include: lead, tin, aluminum, copper, zirconium, titanium, molybdenum, beryllium, vanadium, niobium, and steel.

Examples of products produced by this process are: collapsible tubes, fire extinguisher cases, shock absorber cylinders, automotive pistons, and gear blanks.

Warm extrusion

Warm extrusion is done above room temperature, but below the recrystallization temperature of the material. It is usually used to achieve the proper balance of required forces, ductility and final extrusion properties.

Q.79 What are the desirable properties of an insulation material? **(8)**

Ans: DESIRABLE PROPERTIES OF INSULATION

Not all properties are significant for all materials or applications. In some applications, however, omitted properties may assume extreme importance (i.e. when insulations must be compatible with chemically corrosive atmospheres.)

The following properties are referenced only according to their significance in meeting design criteria of specific applications.

1. THERMAL PROPERTIES OF INSULATION

Thermal properties are the primary consideration in choosing insulations.

a. Temperature limits: Upper & lower temperatures within which the material must retain all its properties.

b. Thermal conductance "C": The rate of heat flow for the actual thickness of a material.

c. Thermal conductivity "K": The rate of heat flow based on 25 mm (one inch) thickness.

d. Emissivity "E": Significant when the surface temperature of the insulation must be regulated as with moisture condensation or personnel protection.

e. Thermal resistance "R": The overall resistance of a "system" to the flow of heat.

f. Thermal transmittance "U": The overall conductance of heat flow through a "system".

2. MECHANICAL AND CHEMICAL PROPERTIES OF INSULATION

Properties other than thermal must be considered when choosing materials for specific applications.

Among them are:

a. Alkalinity (pH or acidity): Significant when corrosive atmospheres are present. Also insulation must not contribute to corrosion of the system.

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b. Appearance: Important in exposed areas and for coding purposes.

c. Breaking load: In some installations the insulation material must "bridge" over a discontinuity in its support.

d. Capillarity: Must be considered when material may be in contact with liquids.

e. Chemical reaction: Potential fire hazards exist in areas where volatile chemicals are present. Corrosion resistance must also be considered.

f. Chemical resistance: Significant when the atmosphere is salt or chemical laden.

g. Coefficient of expansion and contraction: Enters into the design and spacing of expansion/contraction joints and/or the use of multiple layer insulation applications.

h. Combustibility: One of the measures of a material's contribution to a fire hazard.

i. Compressive strength: Important if the insulation must support a load or withstand mechanical abuse without crushing. If, however, cushioning or filling in space is needed as in expansion/contraction joints, low compressive strength materials are specified.

j. Density: A material's density affects other properties of that material, especially thermal properties.

k. Dimensional stability: Significant when the material is exposed to atmospheric and mechanical abuse such as twisting or vibration from thermally expanding pipe.

l. Fire retardancy: Flame spread and smoke developed ratings should be considered.

m. Hygroscopicity: Tendency of a material to absorb water vapor from the air.

n. Resistance to ultraviolet light: Significant if application is outdoors.

o. Resistance to fungal or bacterial growth: Is necessary in food or cosmetic process areas.

p. Shrinkage: Significant on applications involving cements and mastics.

q. Sound absorption coefficient: Must be considered when sound attenuation is required, as it is in radio stations, some hospital areas, etc.

r. Sound transmission loss value: Significant when constructing a sound barrier.

s. Toxicity: Must be considered in food processing plants and potential fire hazard areas.

Q.80 Explain dielectric loss and loss angle. **(6)**

Ans: Dielectric loss can be defined as the loss of energy which eventually produces a rise in temperature of a dielectric placed in an alternating electrical field. Dielectric losses result from the heating effect on the dielectric material between the conductors. Power from the source is used in heating the dielectric. The heat produced is dissipated into the surrounding medium. When there is no potential difference between two conductors, the atoms in the dielectric material between them are normal and the orbits of the electrons are circular. When there is a potential difference between two conductors, the orbits of the electrons change. The excessive negative charge on one conductor repels electrons on the dielectric toward the positive conductor and thus distorts the orbits of the electrons. A change in the path of electrons requires more energy, introducing a power loss. And the dielectric loss angle is given by the difference between 90° and the dielectric phase angle.

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Q.81 Write notes on:
(i) Zone refining.
(ii) Soft ferrites and their applications **(7 x 2)**

Ans (i) Zone refining is a method of separation by melting in which a molten zone traverses a long ingot of impure metal or chemical. In its common use for purification, the molten region melts impure solid at its forward edge and leaves a wake of purer material solidified behind it as it moves through the ingot. The impurities concentrate in the melt, and are moved to one end of the ingot. **Zone refining** was developed by William Gardner Pfann in Bell Labs as a method to prepare high purity materials for manufacturing transistors. Its early use was on germanium for this purpose, but it can be extended to virtually any solute-solvent system having an appreciable concentration difference between solid and liquid phases at equilibrium. This process is also known as the **Float zone process**, particularly in semiconductor materials processing.
In zone refining, solutes are segregated at one end of the ingot in order to purify the remainder, or to concentrate the impurities for analytical or other purposes. In **zone leveling**, the objective is to distribute solute evenly throughout the purified material, which may be sought in the form of a single crystal. For example, in the preparation of a transistor or a semiconductor diode, an ingot of germanium is first purified by zone refining. Then a small amount of antimony is placed in the molten zone, which is passed through the pure germanium. With the proper choice of rate of heating and other variables, the antimony can be spread evenly through the germanium. This technique is also used for the preparation of silicon for use in computer chips

(ii)Ferrites are dark grey or black ceramic materials. They are very hard, brittle and chemically inert. Most modern magnetically soft ferrites have a cubic (spinel) structure. The general composition of such ferrites is $MeFe_2O_4$ where Me represents one or several of the divalent transition metals such as manganese (Mn), zinc (Zn), nickel (Ni), cobalt (Co), copper (Cu), iron (Fe) or magnesium (Mg).
The most popular combinations are manganese and zinc (MnZn) or nickel and zinc (NiZn). These compounds exhibit good magnetic properties below a certain temperature, called the Curie Temperature (TC). They can easily be magnetized and have a rather high intrinsic resistivity. These materials can be used up to very high frequencies without laminating, as is the normal requirement for magnetic metals.
NiZn ferrites have a very high resistivity and are most suitable for frequencies over 1 MHz, however, MnZn ferrites exhibit higher permeability (mi) and saturation induction levels (Bs) and are suitable up to 3 MHz. For certain special applications, single crystal ferrites can be produced, but the majority of ferrites are manufactured as polycrystalline ceramics.
Soft ferrite cores are used wherever effective coupling between an electric current and a magnetic flux is required. They form an essential part of inductors and transformers used in today's main application areas:
· Telecommunications

· Power conversion

· Interference suppression.

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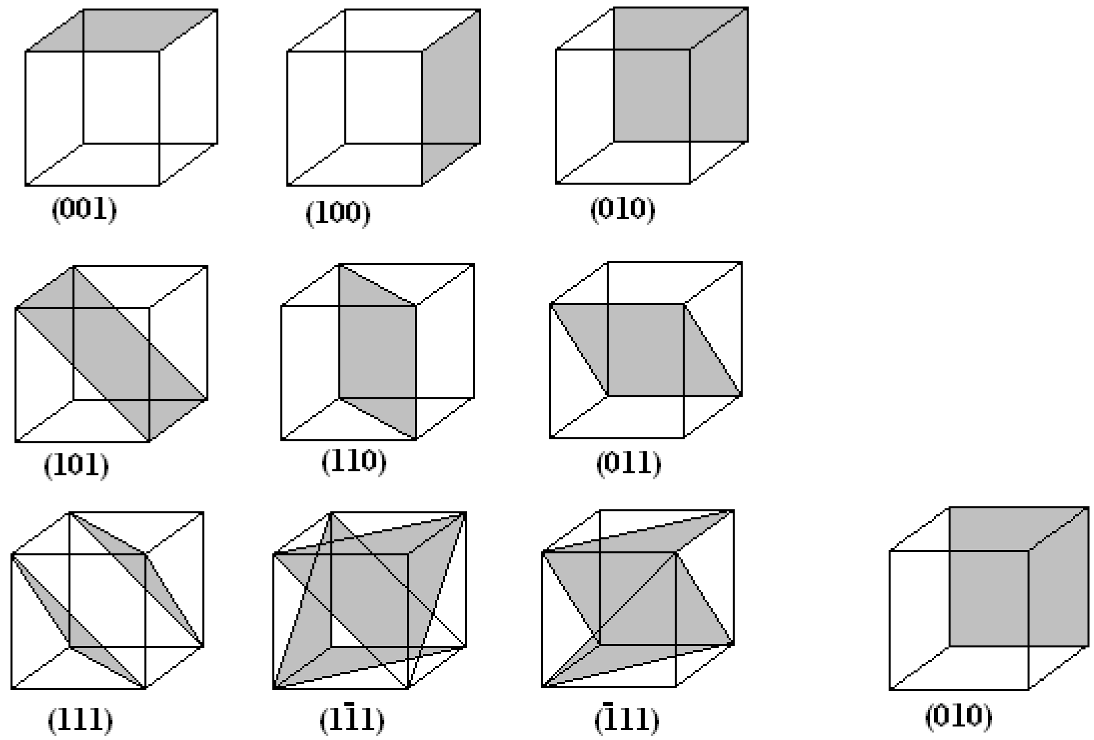
Q.82 What are Miller indices? What are their significances? Draw a (110) and a $(\bar{1}\bar{1}1)$ plane inside a cubic unit cell. **(2 + 4)**

Ans: Miller indices are a notation system in crystallography for planes and directions in crystal (Bravais) lattices. In particular, a family of lattice planes is determined by three integers h, k, and l, the *Miller indices*. They are written (h, k, l) and denote planes orthogonal to a direction in the basis of the reciprocal lattice vectors. By convention, negative integers are written with a bar, as in $\bar{3}$ for − 3. The integers are usually written in lowest terms, i.e. their greatest common divisor should be 1.

There are also several related notations. [ ], with square instead of round brackets, denotes a direction in the basis of the direct lattice vectors instead of the reciprocal lattice. The notation { }denotes all planes that are equivalent to by the symmetry of the crystal.

The precise meaning of this notation depends upon a choice of lattice vectors for the crystal. Usually, three primitive lattice vectors are used. However, for cubic crystal systems, the cubic lattice vectors are used even when they are not primitive (e.g., as in body-centered and face-centered crystals).



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Q.83 Explain the term 'welding'. Briefly explain the distinguishing features of the follow[illegible] method of welding : (i) pressure welding (ii) fusion welding; (iii) electric arc welding. **(8)**

Ans: Welding is the process of joining two metallic pieces by the application of heat or pressure or both. This process utilises the property of the material called fusion.
Pressure welding: Also called 'cold welding', pressure is applied to the workpieces through dies or rolls. Because of the plastic deformation involved, it is necessary that at least one (but preferably both) of the mating parts be ductile. Prior to welding, the interface is degreased, wire-brushed, and wiped to remove oxide smudges. Pressure welding can be used to join small workpieces made of soft, ductile metals.
It is now known that the force of adhesion following first contact can be augmented by pressing the metals tightly together, increasing the duration of contact, raising the temperature of the workpieces, or any combination of the above. Research has shown that even for very smooth metals, only the high points of each surface, called asperities, touch the opposing piece. Perhaps as little as a few thousandths of a percent of the total surface is involved. However, these small areas of taction develop powerful molecular connections; electron microscope investigations of contact points reveal that an actual welding of the two surfaces takes place after which it is impossible to discern the former asperitic interface. If the original surfaces are sufficiently smooth the subatomic attractions between contact points eventually draw the two pieces completely together and eliminate even the macroscopic interface.
Exposure to oxygen or certain other reactive compounds produces surface layers that reduce or completely eliminate the pressure welding effect. This is especially true if, for example, a metal oxide has mechanical properties similar to those of the parent element (or softer), in which case surface deformations do not crack the oxide film. The reason pressure welding does not normally occur between metals on earth is because there is a very fine layer of oxidized metal due to the atmosphere, and even earth-made metals taken to space would retain this layer and not cold-weld.
(ii) **fusion welding** : Fusion welding involves a heat source and may involve the use of a filler material such as a consumable electrode or a wire fed into the weld pool. These processes also use a protective layer between the atmosphere and the molten metal, either in the form of gas shielding or a flux which melts to give a viscous slag on the weld metal that eventually solidifies and can be removed. There are several different types of fusion welding processes that can be used e.g. Manual Metal Arc (MMA), Submerged arc welding (SAW), Metal inert gas (MIG), Tungsten inert gas (TIG), Laser, Electron Beam etc.
(iii) **electric arc welding**. : in this type of welding, heat is supplied by the electric arc between electrode and the workpiece, arc caused by the potential difference between electrode and the work piece. The supply source can be ac or dc. And electrode can be of consumable or non consumable type. Eg SMAW, MIG, TIG.

Q.84 What is an energy band? Why does the Fermi level in an intrinsic semiconductor lies in the middle of the energy gap? **(2 + 6)**

Ans: Any solid has a large number of bands. In theory, it can be said to have infinitely many bands (just as an atom has infinitely many energy levels). However, all but a few lie at

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energies so high that any electron that reaches those energies escapes from the solid. Th bands are usually disregarded.

Bands have different widths, based upon the properties of the atomic orbitals from which they arise. Also, allowed bands may overlap, producing (for practical purposes) a single large band.

Metals contain a band that is partly empty and partly filled regardless of temperature. Therefore, they have very high conductivity.

The lowermost, almost fully occupied band in an insulator or semiconductor is called the valence band by analogy with the valence electrons of individual atoms. The uppermost, almost unoccupied band is called the conduction band because only when electrons are excited to the conduction band can current flow in these materials. The difference between insulators and semiconductors is only that the forbidden band gap between the valence band and conduction band is larger in an insulator, so that fewer electrons are found there and the electrical conductivity is lower. Because one of the main mechanisms for electrons to be excited to the conduction band is due to thermal energy, the conductivity of semiconductors is strongly dependent on the temperature of the material.

This band gap is one of the most useful aspects of the band structure, as it strongly influences the electrical and optical properties of the material. Electrons can transfer from one band to the other by means of carrier generation and recombination processes. The band gap and defect states created in the band gap by doping can be used to fabricate semiconductor devices such as solar cells, diodes, transistors, laser diodes, and others.

Fermi Level in an Intrinsic Semiconductor

In an Intrinsic Semiconductor, Fermi level (E_f) lies in the middle of energy gap or mid way between the conduction and valence bands.

Let,

n_v = No. of electrons in the valence band

n_c = No. of electrons in the conduction band

N = No. of electrons in both bands

$= n_v + n_c$

After considering some assumptions, Let the zero energy reference level is arbitrarily taken at the top of the valence band.

Therefore, no. of electrons in the conduction band, $n_c = N.P\ (E_g)$

Where $P\ (E_g)$ = probability of an electro having energy E_g

Fermi-Dirac probability distribution function gives its value given below:

$$P\ (E) = 1\ /\ 1+ e^{(E - E_F)/ KT}$$

Therefore, $$P\ (E_g) = 1\ /\ 1+ e^{(E_g - E_F)/ KT}$$

Therefore, $$n_c = 1\ /\ 1+ e^{(E_g - E_F)/ KT}$$

Number of electrons in the valance band is

$$n_v = N.P\ (0)$$

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By putting E = 0 in the Fermi – Dirac probability distribution function,

$$P(0) = 1 / 1+ e^{(0 - E_F)/KT} = 1 / 1+ e^{- E_F / KT}$$

Therefore, $n_v = N / 1+ e^{- E_F / KT}$

Now, $N = n_v + n_c$

$$= N / 1+ e^{- E_F / KT} + 1 / 1+ e^{(E_g - E_F)/ KT}$$

After Simplification, we get

$$E_F = E_g / 2$$

This shows that in an Intrinsic Semiconductor, Fermi level (E_f) lies in the middle of energy gap or mid way between the conduction and valence bands.

Q.85 Distinguish between "doping" and "alloying". Which of the two should be resorted to for changing the mechanical properties and why? **(6)**

Ans: **Doping** is the process of intentionally introducing impurities into a pure (also referred to as *intrinsic*) semiconductor in order to change its electrical properties, whereas alloying means making one solid solution or homogeneous mixture of two or more elements, at least one of which is a metal, which itself has metallic properties. It usually has different properties from those of its component elements. Alloying one metal with others often enhances its properties.

Q.86 Show that the electronic polarizability is proportional to the volume of the atom. What is the effect of temperature on the polarization of ferroelectric material? **(5 + 3)**

Ans: Dielectric strength has the following meanings:

* For an insulating material, **Dielectric strength** represents the maximum electric field strength that it can withstand intrinsically without breaking down, i.e., without experiencing failure of its insulating properties.

* For a given configuration of dielectric material and electrodes, the minimum electric field that produces breakdown.

The theoretical dielectric strength of a material is an intrinsic property of the bulk material and is dependent on the configuration of the material or the electrodes with which the field is applied. At breakdown, the electric field frees bound electrons. If the applied electric field is sufficiently high, free electrons may become accelerated to velocities that can liberate additional electrons during collisions with neutral atoms or molecules in a process called avalanche breakdown. Breakdown occurs quite abruptly (typically in nanoseconds)., resulting in the formation of an electrically conductive path and a disruptive discharge through the material. For solid materials, a breakdown event severely degrades, or even destroys, its insulating capability.

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Q.87 What are the functions of oxide layer in a high quality IC? Explain. **(6)**

Ans: The functions of the oxide layer are to:

(i) mask against diffusion or ion-implant

(ii) passivate the surface electrically and chemically

(iii)isolate one device from another

(iv)act as a component in MOS devices

Q.88 Differentiate "ion implantation" and "metallization" processes in the fabrication of ICs. **(8)**

Ans: Ion implantation equipment typically consists of an ion source, where ions of the desired element are produced, an accelerator, where the ions are electrostatically accelerated to a high energy, and a target chamber, where the ions impinge on a target, which is the material to be implanted. Each ion is typically a single atom, and thus the actual amount of material implanted in the target is the integral over time of the ion current. This amount is called the dose. The currents supplied by implanters are typically small (microamperes), and thus the dose which can be implanted in a reasonable amount of time is small. Thus, ion implantation finds application in cases where the amount of chemical change required is small. **Metallization** is the fabrication step in which proper interconnection of circuit elements is made. Aluminum is a popular metal used to interconnect ICs, both to make ohmic contact to the devices and connect these to the bonding pads on the chip's edge. Aluminum adheres well to both silicon and silicon dioxide, can be easily vacuum deposited (since it has a low boiling point), and has high conductivity. In addition to pure aluminum, alloys of aluminum are used to form IC interconnections for different performance-related reasons. For example, small amounts of copper are added to reduce the potential for electromigration effects (in which current applied to the device induces mass transport of the metal). Small amounts of silicon also are added to aluminum metallization to reduce the formation of metal "spikes" that occur over contact holes.

Q.89 Explain with sketch the process of "forging". **(7)**

Ans: Forging is the process by which metal is heated and is shaped by plastic deformation by suitably applying compressive force. Usually the compressive force is in the form of hammer blows using a power hammer or a press.

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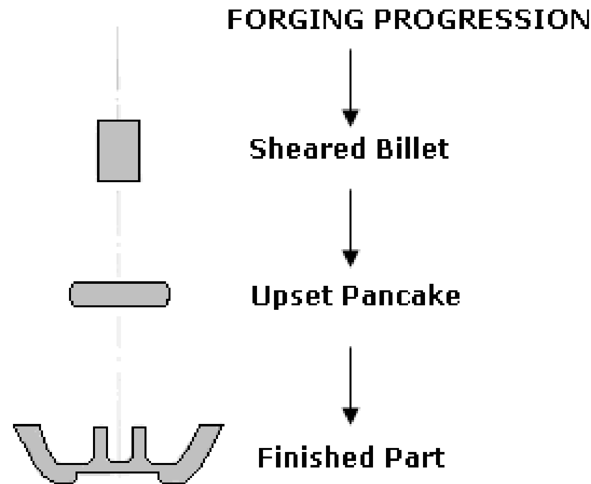
Forging refines the grain structure and improves physical properties of the metal. With pr[...] design, the grain flow can be oriented in the direction of principal stresses encountered i[...] actual use. Grain flow is the direction of the pattern that the crystals take during plastic deformation. Physical properties (such as strength, ductility and toughness) are much better in a forging than in the base metal, which has, crystals randomly oriented.



Forgings are consistent from piece to piece, without any of the porosity, voids, inclusions and other defects. Thus, finishing operations such as machining do not expose voids, because there aren't any. Also coating operations such as plating or painting are straightforward due to a good surface, which needs very little preparation.

Q.90 What are the objectives of annealing? Explain annealing and spheroidising processes. **(4 + 3)**

Ans: Annealing, is a heat treatment wherein a material is altered, causing changes in its properties such as strength and hardness. It is a process that produces conditions by heating and maintaining a suitable temperature, and then cooling. Annealing is used to induce ductility, relieve internal stresses, refine the structure and improve cold working properties.

Annealing occurs by the diffusion of atoms within a solid material, so that the material progresses towards its equilibrium state. Heat is needed to increase the rate of diffusion by providing the energy needed to break bonds. The movement of atoms has the effect of redistributing and destroying the dislocations in metals and (to a lesser extent) in ceramics. This alteration in dislocations allows metals to reform more easily, so increases their ductility.

There are three stages in the annealing process, the first being the recovery phase, which results in softening of the metal through removal of crystal defects (the primary type of which is the linear defect called a dislocation) and the internal stresses which they cause. The second phase is recrystallization, where new grains nucleate and grow to replace those deformed by internal stresses. If annealing is allowed to continue once recrystallization has been completed, grain growth will occur, in which the microstructure starts to coarsen and may cause the metal to have less than satisfactory mechanical properties.

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Spheroidising is the process that applies more to the hypereutectoid steels (above 0,8%). The process involves heating the metal to between 600°C and 650°C and holding it at the selected temperature for a period of time the cementite changes from a lamella formation to a formation based on an alpha ferrite matrix with particles of spheroidal cementite (Fe3C) are embedded. This resulting steel has improved ductility and toughness compared to the original steel with reduced hardness and strength.

Q.91 What are the properties and applications of bakelite and transformer oil? **(6)**

Ans: The **Transformer oil** helps cool the transformer. Because it also provides part of the electrical insulation between internal live parts, transformer oil must remain stable at high temperatures over an extended period. To improve cooling of large power transformers, the oil-filled tank may have external radiators through which the oil circulates by natural convection. Very large or high-power transformers (with capacities of millions of KVAs) may also have cooling fans, oil pumps, and even oil-to-water heat exchangers.

Large, high-voltage transformers undergo prolonged drying processes, using electrical self-heating, the application of a vacuum, or both to ensure that the transformer is completely free of water vapor before the cooling oil is introduced. This helps prevent corona formation and subsequent electrical breakdown under load.

Oil filled transformers with conservators (an oil tank above the transformer) tend to be equipped with Buchholz relays. These are safety devices that can sense gas buildup inside the transformer (a side effect of corona or an electric arc inside the windings) and then switch off the transformer. Transformers without conservators are usually equipped with sudden pressure relays, which perform a similar function as the Buchholz relay.

Bakelite is a material based on the thermosetting phenol formaldehyde resin. Formed by the reaction under heat and pressure of phenol (a toxic, colourless crystalline solid) and formaldehyde (a simple organic compound), generally with a wood flour filler, it was the first plastic made from synthetic components. It was used for its electrically nonconductive and heat-resistant properties in radio and telephone casings and electrical insulators, and was also used in such diverse products as kitchenware, jewellery, pipe stems, and children's toys.

Today, Bakelite is manufactured and produced in the form of sheets, rods and tubes for hundreds of industrial applications in the electronics, power generation and aerospace industries, and under a variety of commercial brand names, including Garolite.

Bakelite sheet is a hard, dense material made by applying heat and pressure to layers of paper or glass cloth impregnated with synthetic resin. These layers of laminations are usually of cellulose paper, cotton fabrics, synthetic yarn fabrics, glass fabrics or unwoven fabrics. When heat and pressure are applied to the layers, a chemical reaction (polymerization) transforms the layers into a high-pressure thermosetting industrial laminated plastic.

Although not extensively used as an industrial manufacturing material any more, in the past Bakelite was used in myriad applications, such as saxophone mouthpieces, cameras, solid-body electric guitars, rotary-dial telephones, early machine guns, and appliance casings. It was at one point considered for the manufacture of coins, due to a shortage of traditional manufacturing material.

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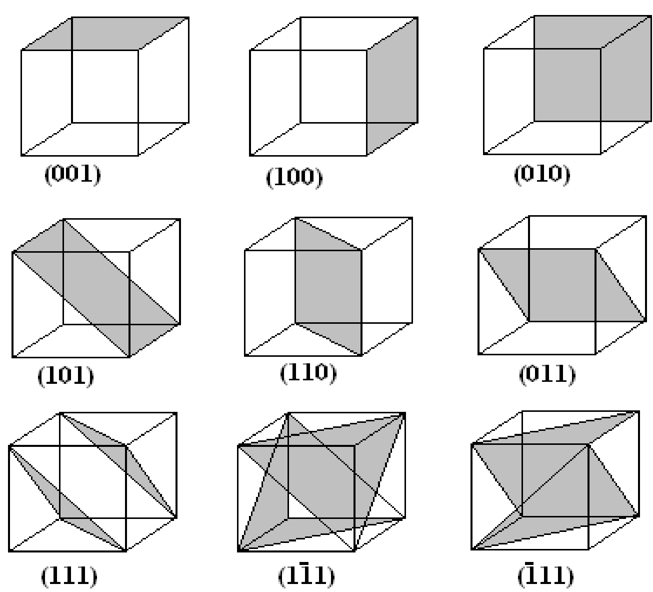
Q.92 Compare and differentiate the properties of common semi-conducting materials and com... dielectric materials. **(8)**

Ans:

Semi-conducting materials	Dielectric materials
1) These are the materials whose valence electrons are bounded somewhat loosely to their atom.	1) These are the materials in which valence electrons used are bounded very tightly to their parent atoms.
2) They require energy less than dielectrics and more than good conductors to remove an electron from the parent atom.	2) They require very large electric field to remove them from the attraction of the nuclei.
3)They have: (i) an empty conduction band (ii) almost filled valence band (iii) Very narrow energy gap (of about 1eV) separating the two bands.	3) They have: (i) a full valence band (ii) an empty conduction band (iii) a large energy gap separating the two bands.

Q.93 Draw sketches illustrating a (100) plane, a (110) plane, and a (111) plane in a cubic unit cell. How many equivalent {100} planes are there in a cubic crystal? **(8)**

Ans:



In totality, 6 equivalent planes to {100} are there in a cubic crystal.

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Q.94 Explain the electric polarization and the electric susceptibility in the context of dielectrics. **(8)**

Ans: Polarization of Dielectric

If a material contains polar molecules, they will generally be in random orientations when no electric field is applied. An applied electric field will polarize the material by orienting the dipole moments of polar molecules. This decreases the effective electric field between the plates and will increase the capacitance of the parallel plate structure. The dielectric must be a good electric insulator so as to minimize any DC leakage current through a capacitor.

Electric susceptibility

The electric susceptibility χ_e of a dielectric material is a measure of how easily it polarizes in response to an electric field. This, in turn, determines the electric permittivity of the material and thus influences many other phenomena in that medium, from the capacitance of capacitors to the speed of light.

It is defined as the constant of proportionality (which may be a tensor) relating an electric field E to the induced dielectric polarization density P such that

$$\mathbf{P} = \varepsilon_0 \chi_e \mathbf{E},$$

Where ε_0 is the electric permittivity of free space

The susceptibility of a medium is related to its relative permittivity ε_r by

$$\chi_e = \varepsilon_r - 1.$$

So in the case of a vacuum,

$$\chi_e = 0.$$

Q.95 Describe Ferrites for high frequency transformers and computer memory cores. **(8)**

Ans: Ferrites are usually non-conductive ferrimagnetic ceramic compounds derived from iron oxides such as hematite (Fe_2O_3) or magnetite (Fe_3O_4) as well as oxides of other metals. Ferrites are, like most other ceramics, hard and brittle. In terms of the magnetic properties, ferrites are often classified as "soft" and "hard" which refers to the low or high coercivity of their magnetism, respectively.

Ferrite cores are used in electronic inductors, transformers, and electromagnets where the high electrical resistance of the ferrite leads to very low eddy current losses. They are commonly seen as a lump in a computer cable, called a ferrite bead, which helps to prevent high frequency electrical noise (radio frequency interference) from exiting or entering the equipment.

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Early computer memories stored data in the residual magnetic fields of hard ferrite co which were assembled into arrays of core memory. Ferrite powders are used in the coatings o magnetic recording tapes. One such type of material is iron (III) oxide.

Q.96 Outline a procedure for photolithography in the fabrication of electronic devices. What are the limitations of this procedure? **(8)**

Ans: Photolithography is the process of transferring geometric shapes on a mask to the surface of a semiconductor wafer. The steps involved in the photolithographic process are wafer cleaning; barrier layer formation; photoresist application; soft baking; mask alignment; exposure and development; and hard-baking.

Wafer Cleaning, Barrier Formation and Photoresist Application

In the first step, the wafers are chemically cleaned to remove particulate matter on the surface as well as any traces of organic, ionic, and metallic impurities. After cleaning, silicon dioxide, which serves as a barrier layer, is deposited on the surface of the wafer. After the formation of the SiO2 layer, photoresist is applied to the surface of the wafer. High-speed centrifugal whirling of silicon wafers is the standard method for applying photoresist coatings in IC manufacturing. This technique, known as "Spin Coating," produces a thin uniform layer of photoresist on the wafer surface.

Positive and Negative Photoresist

There are two types of photoresist: positive and negative. For positive resists, the resist is exposed with UV light wherever the underlying material is to be removed. In these resists, exposure to the UV light changes the chemical structure of the resist so that it becomes more soluble in the developer. The exposed resist is then washed away by the developer solution, leaving windows of the bare underlying material. In other words, "whatever shows, goes." The mask, therefore, contains an exact copy of the pattern which is to remain on the wafer.

Negative resists behave in just the opposite manner. Exposure to the UV light causes the negative resist to become polymerized, and more difficult to dissolve. Therefore, the negative resist remains on the surface wherever it is exposed, and the developer solution removes only the unexposed portions. Masks used for negative photoresists, therefore, contain the inverse (or photographic "negative") of the pattern to be transferred. The figure below shows the pattern differences generated from the use of positive and negative resist.

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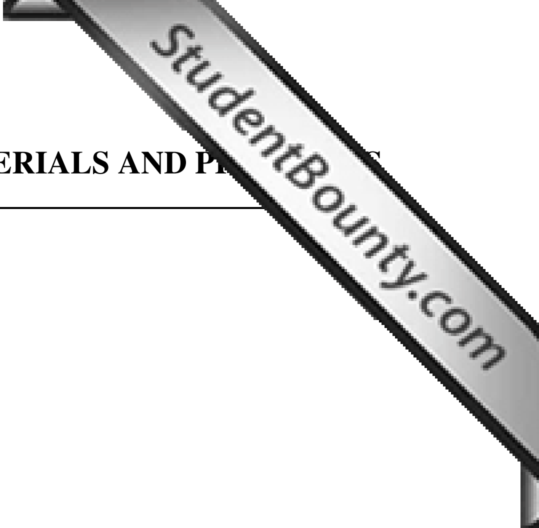

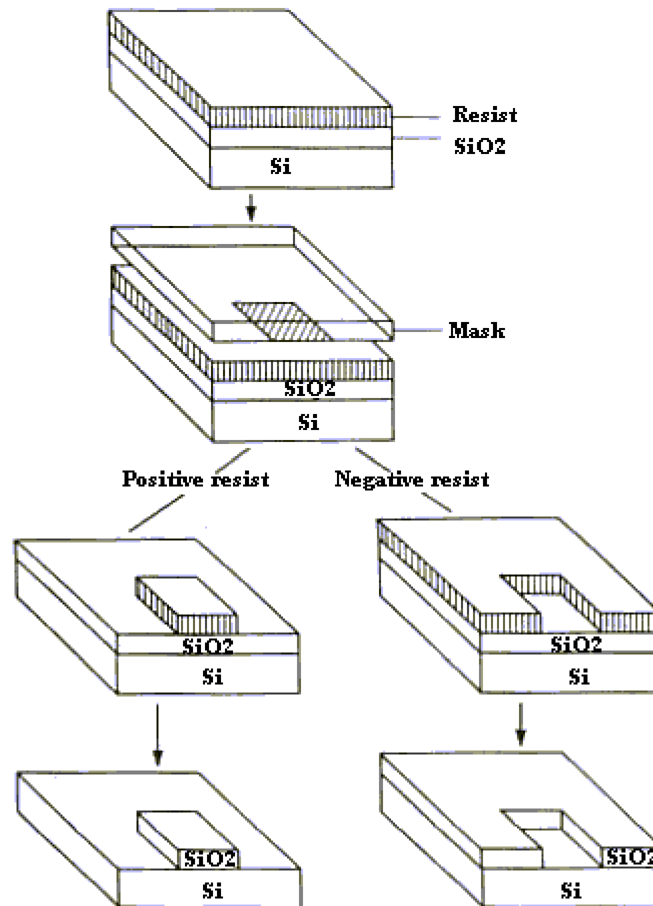

Negative resists were popular in the early history of integrated circuit processing, but positive resist gradually became more widely used since they offer better process controllability for small geometry features. Positive resists are now the dominant type of resist used in VLSI fabrication processes.

Soft-Baking

Soft-baking is the step during which almost all of the solvents are removed from the photoresist coating. Soft-baking plays a very critical role in photo-imaging. The photoresist coatings become photosensitive, or imageable, only after softbaking. Oversoft-baking will degrade the photosensitivity of resists by either reducing the developer solubility or actually destroying a portion of the sensitizer. Undersoft-baking will prevent light from reaching the sensitizer. Positive resists are incompletely exposed if considerable solvent remains in the

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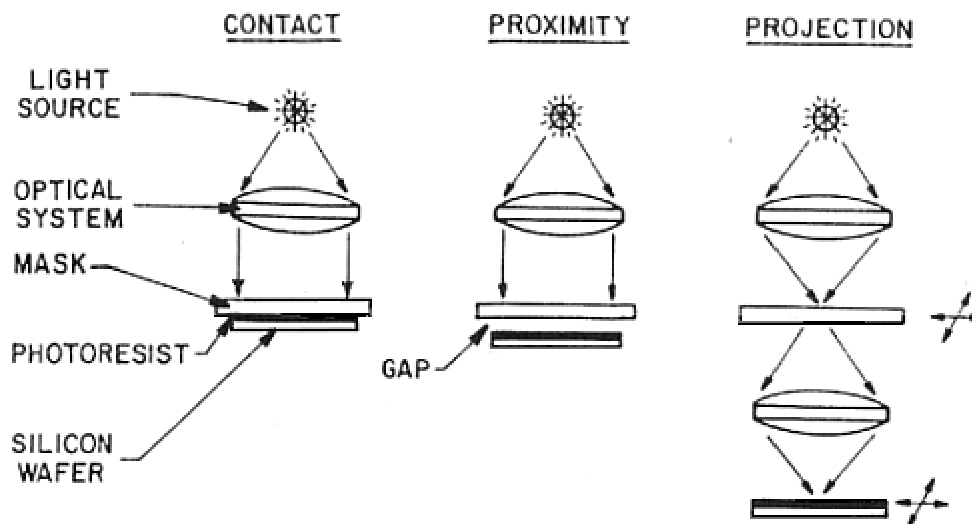
coating. This undersoft-baked positive resists is then readily attacked by the developer in both exposed and unexposed areas, causing less etching resistance.

Mask Alignment and Exposure

One of the most important steps in the photolithography process is mask alignment. A mask or "photomask" is a square glass plate with a patterned emulsion of metal film on one side. The mask is aligned with the wafer, so that the pattern can be transferred onto the wafer surface. Each mask after the first one must be aligned to the previous pattern.

Once the mask has been accurately aligned with the pattern on the wafer's surface, the photoresist is exposed through the pattern on the mask with a high intensity ultraviolet light. There are three primary exposure methods: contact, proximity, and projection. They are shown in the figure below.



Contact Printing

In contact printing, the resist-coated silicon wafer is brought into physical contact with the glass photomask. The wafer is held on a vacuum chuck, and the whole assembly rises until the wafer and mask contact each other. The photoresist is exposed with UV light while the wafer is in contact position with the mask. Because of the contact between the resist and mask, very high resolution is possible in contact printing (e.g. 1-micron features in 0.5 microns of positive resist). The problem with contact printing is that debris, trapped between the resist and the mask, can damage the mask and cause defects in the pattern.

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Proximity Printing

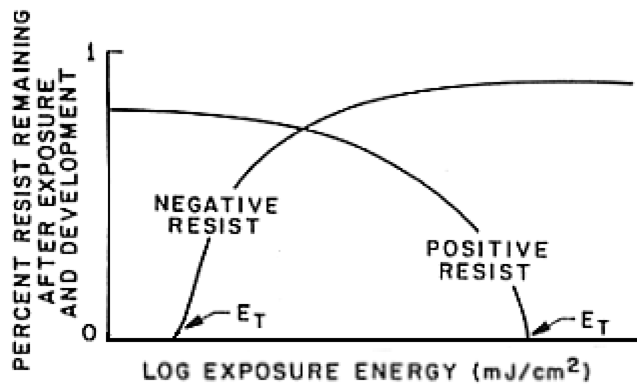
The proximity exposure method is similar to contact printing except that a small gap, 10 to 25 microns wide, is maintained between the wafer and the mask during exposure. This gap minimizes (but may not eliminate) mask damage. Approximately 2- to 4-micron resolution is possible with proximity printing.

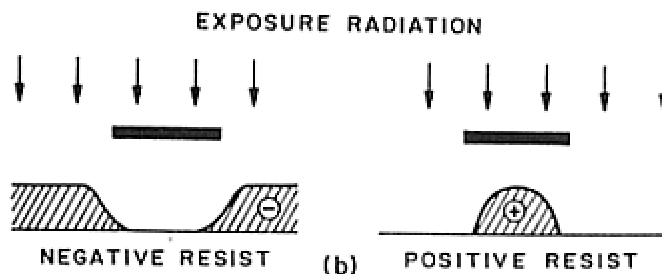
Projection Printing

Projection printing, avoids mask damage entirely. An image of the patterns on the mask is projected onto the resist-coated wafer, which is many centimeters away. In order to achieve high resolution, only a small portion of the mask is imaged. This small image field is scanned or stepped over the surface of the wafer. Projection printers that step the mask image over the wafer surface are called step-and-repeat systems. Step-and-repeat projection printers are capable of approximately 1-micron resolution.

Development

One of the last steps in the photolithographic process is development. The figure below shows response curves for negative and positive resists after exposure and development.





(a) Resist exposure characteristics. (b) Resist after development.

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At low-exposure energies, the negative resist remains completely soluble in the devel solution. As the exposure is increased above a threshold energy Et, more of the resist fil remains after development. At exposures two or three times the threshold energy, very little of the resist film is dissolved. For positive resists, the resist solubility in its developer is finite even at zero-exposure energy. The solubility gradually increases until, at some threshold, it becomes completely soluble. These curves are affected by all the resist processing variables: initial resist thickness, prebake conditions, developer chemistry, developing time, and others.

Hard-Baking

Hard-baking is the final step in the photolithographic process. This step is necessary in order to harden the photoresist and improve adhesion of the photoresist to the wafer surface.

Q.97 Distinguish the following with suitable examples:-

a. Ionic and covalent types of bonding.
b. Lattice and cohesive energy.
c. Ionisation energy and electron affinity. **(3+3+3)**

Ans: (i) An **ionic bond** (or electrovalent bond) is a type of chemical bond that can often form between metal and non-metal ions (or polyatomic ions such as ammonium) through electrostatic attraction. Or we can say, it is a bond formed by the attraction between two oppositely charged ions.

For example, common table salt is sodium chloride. When sodium (Na) and chlorine (Cl) are combined, the sodium atoms each lose an electron, forming a cation (Na+), and the chlorine atoms each gain an electron to form an anion (Cl-). These ions are then attracted to each other in a 1:1 ratio to form sodium chloride (NaCl).

Na + Cl → Na+ + Cl- → NaCl

A **covalent bond** is a form of chemical bonding that is characterized by the sharing of pairs of electrons between atoms, or between atoms and other covalent bonds. Or we can say that, attraction-to-repulsion stability that forms between atoms when they share electrons is known as covalent bonding.

Covalent bonding includes many kinds of interactions, including σ-bonding, π-bonding, metal-metal bonding, agostic interactions, and three-center two-electron bonds.

For example, in the molecule H_2, the hydrogen atoms share the two electrons via covalent bonding.

(ii) The lattice energy of an ionic solid is a measure of the strength of bonds in that ionic compound. It is given the symbol U and is equivalent to the amount of energy required to separate a solid ionic compound into gaseous ions. Lattice energy can also be considered as the energy given off when gaseous ions form an ionic solid. It is dependent on ionic charge and the ionic radius: as the charge of the ions increases, the magnitude of the lattice energy increases (becomes more negative), and as the radius decreases (the ions in the ionic solid

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move closer together), the lattice energy increases. Lattice energy is used primarily in resp... to inorganic, crystalline solids.
Whereas cohesive energy can be defined as the difference between the average energy of the atoms of a solid (especially a crystal) and that of the free atoms.

(iii) Ionization energy can be defined as the energy required to remove an electron from a neutral atom. Whereas Electron affinity is the energy change when a neutral atom attracts an electron to become a negative ion. It can also be stated that Ionization energy is the energy needed to remove an electron from an element, whereas electron affinity is the amount of attraction a substance has for a electron. One is the amount of energy to remove an electron while the other is the likeliness for it to attract an electron.

Q.98 Establish the relation between lattice constant (a) of a cubic crystal and the density of the crystal material. **(4)**

Ans: Let n = no. of molecules per unit cell
M= molecular weight of the crystal material
N = Avogadro number = $6.023 * 10^{23}$

In M gram of material there are N molecules, i.e. weight of N molecules is M gram.

Therefore, weight of n molecules = $\frac{n * M}{N}$ gram = weight of unit cell (ρa^3)

Therefore, $\rho a^3 = \frac{n * M}{N}$, ρ = density of crystal material

$\rho = \frac{n * M}{a^3 * N}$, a = Lattice constant

Q.99 What is meant by crystal imperfections? Classify them in the order of their geometry. Explain the difference between edge and screw dislocations. What is a Burger's vector? **(2+2+4+1)**

Ans: Crystalline solids have a very regular atomic structure: that is, the local positions of atoms with respect to each other are repeated at the atomic scale. These arrangements are called crystal structures, and their study is called crystallography. However, most crystalline materials are not perfect: the regular pattern of atomic arrangement is interrupted by crystal defects. The various types of defects are enumerated here.
Point defects: Point defects are defects which are not extended in space in any dimension. There is no strict limit for how small a "point" defect should be, but typically the term is used to mean defects which involve at most a few extra or missing atoms without an ordered structure of the defective positions. Larger defects in an ordered structure are usually considered dislocation loops. For historical reasons, many point defects especially in ionic crystals are called 'centers': for example the vacancy in many ionic solids is called an F-center.

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* Vacancies are sites which are usually not occupied by an atom and remain unoccupied. If a neighboring atom moves to occupy the vacant site, the vacancy moves in the opposite direction to the site which used to be occupied by the moving atom. The stability of the surrounding crystal structure guarantees that the neighboring atoms will not simply collapse around the vacancy. In some materials, neighboring atoms actually move away from a vacancy, because they can better form bonds with atoms in the other directions. A vacancy (or pair of vacancies in an ionic solid) is sometimes called a Schottky defect.
* Interstitials are atoms which occupy a site in the crystal structure at which there is usually no atom. They are generally high energy configurations. Small atoms in some crystals can occupy interstices without high energy, such as hydrogen in palladium.
* A nearby pair of a vacancy and an interstitial is often called a Frenkel defect or Frenkel pair.
* Impurities occur because materials are never 100% pure. In the case of an impurity, the atom is often incorporated at a regular atomic site in the crystal structure. This is neither a vacant site nor is the atom on an interstitial site and it is called a substitutional defect. The atom is not supposed to be anywhere in the crystal, and is thus an impurity
* Anti-site defects occur in an ordered alloy. For example, some alloys have a regular structure in which every other atom is a different species, for illustration assume that type A atoms sit on the cube corners of a cubic lattice, and type B atoms sit in center of the cubes. If one cube has an A atom at its center, the atom is on a site usually occupied by an atom, but it is not the correct type. This is neither a vacancy nor an interstitial, nor an impurity.
* Topological defects are regions in a crystal where the normal chemical bonding environment is topologically different from the surroundings. For instance, in a perfect sheet of graphite (graphene) all atoms are in rings containing six atoms. If the sheet contains regions where the number of atoms in a ring is different from six, while the total number of atoms remains the same, a topological defect is formed. An example is the Stone Wales defect in nanotubes, which consists of two adjacent 5-membered and two 7-membered atom rings.
* Also amorphous solids may contain defects. These are naturally somewhat hard to define, but sometimes their nature can be quite easily understood. For instance, in ideally bonded amorphous silica all Si atoms have 4 bonds to O atoms and all O atoms have 2 bonds to Si atom. Thus e.g. an O atom with only one Si bond can be considered a defect in silica.
* Complexes can form between different kinds of point defects. For example, if a vacancy encounters an impurity, the two may bind together if the impurity is too large for the lattice. Interstitials can form ‘split interstitial’ or ‘dumbbell’ structures where two atoms effectively share an atomic site, resulting in neither atom actually occupying the site.

Line defects: Line defects can be described by gauge theories.
* Dislocations are linear defects around which some of the atoms of the crystal lattice are misaligned. There are two basic types of dislocations, the EDGE dislocation and the SCREW dislocation. "MIXED" dislocations combining aspects of both types are also common.
*Edge dislocations are caused by the termination of a plane of atoms in the middle of a crystal. In such a case, the adjacent planes are not straight, but instead bend around the edge of the terminating plane so that the crystal structure is perfectly ordered on either side. The

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analogy with a stack of paper is apt: if a half a piece of paper is inserted in a stack of paper, the defect in the stack is only noticeable at the edge of the half sheet.

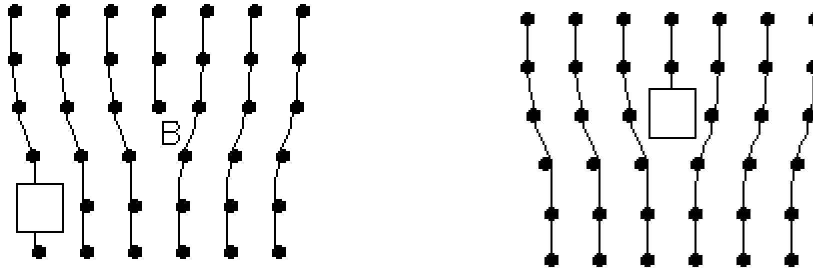

Fig: Edge Dislocation

The screw dislocation is more difficult to visualise, but basically comprises a structure in which a helical path is traced around the linear defect (dislocation line) by the atomic planes of atoms in the crystal lattice.

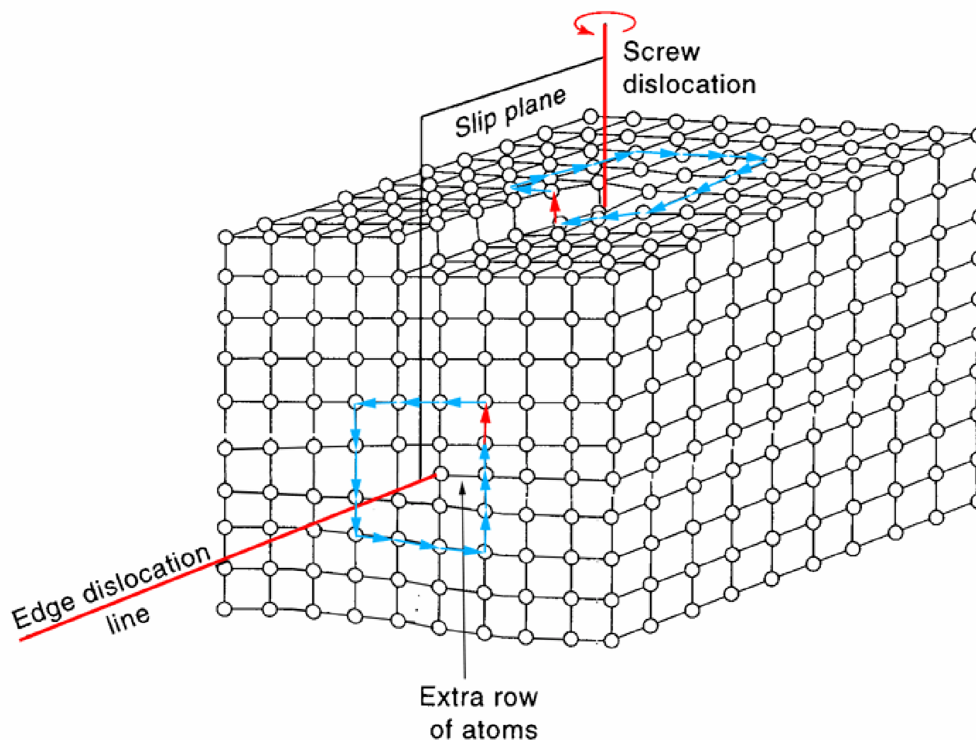

Fig: Screw dislocation

The presence of dislocation results in lattice strain (distortion). The direction and magnitude of such distortion is expressed in terms of a Burgers vector (b). For an edge type, b is perpendicular to the dislocation line, whereas in the cases of the screw type it is parallel. In metallic materials, b is aligned with close-packed crytallographic directions and its magnitude is equivalent to one interatomic spacing.

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Dislocations can move if the atoms from one of the surrounding planes break their bonds and rebond with the atoms at the terminating edge.
It is the presence of dislocations and their ability to readily move (and interact) under the influence of stresses induced by external loads that leads to the characteristic malleability of metallic materials.
Dislocations can be observed using transmission electron microscopy, field ion microscopy and atom probe techniques. Deep level transient spectroscopy has been used for studying the electrical activity of dislocations in semiconductors, mainly silicon.
* Disclinations are line defects corresponding to "adding" or "subtracting" an angle around a line. Basically, this means that if you track the crystal orientation around the line defect, you get a rotation. Usually they play a role only in liquid crystals.

Planar defects

* Grain boundaries occur where the crystallographic direction of the lattice abruptly changes. This usually occurs when two crystals begin growing separately and then meet.

* Anti phase boundaries occur in ordered alloys: in this case, the crystallographic direction remains the same, each side of the boundary has an opposite phase: For example if the ordering is usually ABABABAB, an anti phase boundary takes the form of ABABBABA.

* Stacking faults occur in a number of crystal structures, but the common example is in close-packed structures. Face-centered cubic (fcc) structures differ from hexagonal close packed (hcp) structures only in stacking order: both structures have close packed atomic planes with sixfold symmetry -- the atoms form equilateral triangles. When stacking one of these layers on top of another, the atoms are not directly on top of one another -- the first two layers are identical for hcp and fcc, and labelled AB. If the third layer is placed so that its atoms are directly above those of the first layer, the stacking will be ABA -- this is the hcp structure, and it continues ABABABAB. However there is another location for the third layer, such that its atoms are not above the first layer. Instead, the fourth layer is placed so that its atoms are directly above the first layer. This produces the stacking ABCABCABC, and is actually a cubic arrangement of the atoms. A stacking fault is a one or two layer interruption in the stacking sequence, for example if the sequence ABCABABCAB were found in an fcc structure.

Bulk defects

* Voids are small regions where there are no atoms, and can be thought of as clusters of vacancies.

* Impurities can cluster together to form small regions of a different phase. These are often called precipitates.

BURGER VECTOR

The Burgers vector, often denoted by **b**, is a vector that represents the magnitude and direction of the lattice distortion of dislocation in a crystal lattice. The direction of the vector depends on the plane of dislocation, which is usually on the closest-packed plane of unit cell.

The magnitude of the Burgers vector for a dislocation is of a magnitude equal to the inter-atomic spacing of the material, since a single dislocation will offset the crystal lattice by one close-packed crystallographic spacing unit.

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In edge dislocations, the Burgers vector and dislocation line are at right angles to one ano
In screw dislocations, they are parallel.

The Burgers Vector is significant in determining the strength of a material: it affects solute hardening, precipitation hardening and work hardening, all of which affect yield strength.

Q.100 What is the phase rule and what does it indicate? Using Gibb's phase rule show that eutectoid reaction is non-variant. **(2+2+3)**

Ans: Gibbs' phase rule, is the fundamental rule on which phase diagrams are based. It provides the number of degrees of freedom for a given thermodynamic condition, that is: how many control variables (pressure, temperature, composition, etc) can be altered while maintaining this condition. Mathematically, this number is

$$P + F = C + 2 \ ,$$

Where P is the number of phases in equilibrium coexistence (solid, liquid, gas phases etc) and C is the number of chemical components in the system. The number 2 arises from the two main thermodynamic control parameters, usually temperature and pressure, so that C+2 may be considered as the total number of control parameters necessary to specify a thermodynamic state for a mixture with C components.

At Eutectoid temperature, three phases are in equilibrium i.e. F = 2-3+1 = 0. Thus at eutectoid temperature, compositions are fixed and none of them can be varied arbitrarily. Thus with zero degree of freedom, the Eutectoid reaction is called as non-variant reaction.

Q.101 Explain with suitable diagrams the atomic model of diffusion. How does drift current differ from diffusion current? What is Einstein's relationship? **(4+4+2)**

Ans: Atomic Model of Diffusion

Diffusion occurs as a result of repeated jumps of atoms from their sites to other neighboring sites. Even when atoms jump randomly, a net mass flow can occur down a concentration gradient, when a large number of such jumps take place.
The Unit step in the diffusion process is a single jump by the diffusing species. Diffusion could be of various types.
In Interstitial diffusion, the solute atoms which are small enough to occupy interstitial sites, diffuse by jumping from one interstitial site to another and in Vacancy diffusion, atoms diffuse by interchanging positions with neighboring vacant sites.

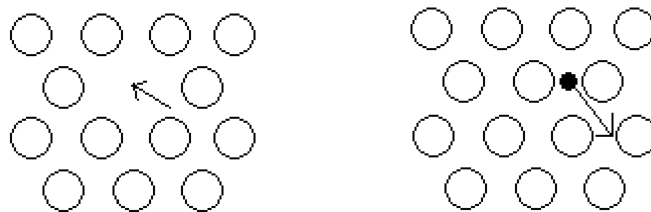

Fig: Vacancy & Interstitial diffusion.

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Eienstein's relationship: $\frac{\mu}{D} = \frac{e}{kT}$ where μ and D are mobility and diffusion coefficient f... a charge carrier (hole or electron).

Drift current is the electric current, or movement of charge carriers, which is due to the applied electric field, often stated as the electromotive force over a given distance. It is distinguished from thermally-induced **Diffusion current**, which results from the random Brownian motion of charge carriers independent of electrical stimulus.

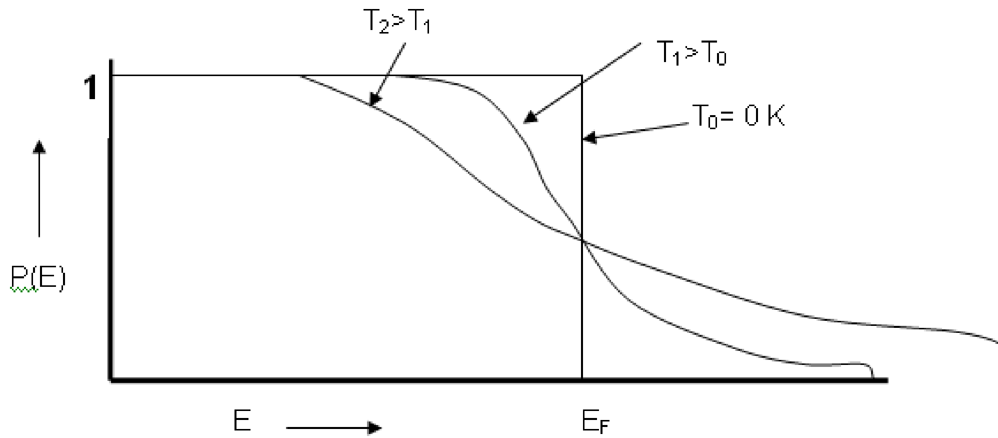
Q.102 Explain with suitable plots the probability of occupancy of energy level E by an electron with

(i) $E < E_F$ (ii) $E = \frac{E_F}{2}$

(iii) $E > E_f$

Also draw a plot between number of electrons and the energy. **(6)**

Ans:



Q.103 Explain the following:

(i) polarizability. (ii) dipole relaxation.

(iii) loss angle. (iv) dielectric breakdown.

Summarize the various factors contributing to breakdown in dielectrics. **(8+2)**

Ans:

(i) Polarizability is the relative tendency of a charge distribution, like the electron cloud of an atom or molecule, to be distorted from its normal shape by an external electric field, which may be caused by the presence of a nearby ion or dipole.

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The electronic Polarizability α is defined as the ratio of the induced dipole moment $\boldsymbol{p}$ o... atom to the electric field $\boldsymbol{E}$ that produces this dipole moment.

$$\boldsymbol{p} = \alpha \boldsymbol{E}$$

Polarizability has the SI units of $C \cdot m^2 \cdot V^{-1}$.

$$\alpha(cm^3) = \frac{10^6}{4\pi\epsilon_0}\alpha(C \cdot m^2 \cdot V^{-1})$$ Where ε_0 is the vacuum permittivity.

(ii) Dipole Relaxation is the process, occupying a certain period of time after a change in the applied electric field, in which the orientation polarization of a substance reaches equilibrium.

(iii) Loss Angle can be defined as the arc-tangent of the electrical dissipation factor.

(iv) Dielectric breakdown means failure or deterioration of the dielectric material due to various reasons. The following three types of breakdown are possible in Dielectrics:

(a) Electrothermal Breakdown – This is caused by the heat produced due to the dielectric loss which is proportional to the intensity of the electric field and the frequency.

(b) Purely Electrical Breakdown – This is basically caused due to the collision ionization by the electrons.

(c) Electrochemical Breakdown – This type of breakdown occurs when the temperature is high and the surrounding air has high humidity.

Q.104 What are the chief characteristics of ferro-electric materials? How do you establish the existence of ferro-electricity in a material? **(3+3)**

Ans: Ferroelectric materials have following characteristics:

a) They have a high dielectric constant which is non-linear i.e. it depends to a considerable extent on the intensity of the electrical field.

b) They exhibit hysteresis loops; i.e. the polarization is not linear function of the applied field.

The most important class of magnetic materials is the Ferro magnets: iron, nickel, cobalt and manganese, or their compounds (and a few more exotic ones as well). The magnetization curve looks very different to that of a diamagnetic or paramagnetic material.

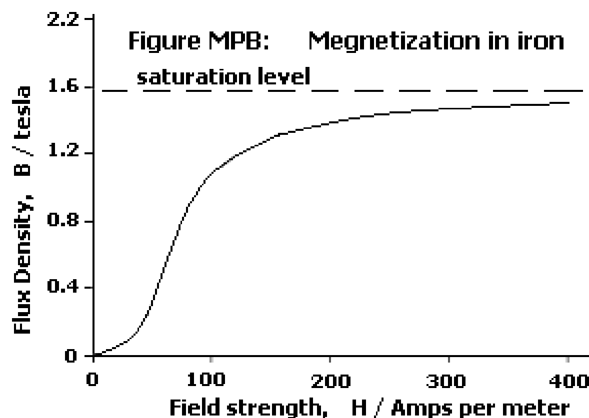

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Figure MPB above shows a typical curve for iron. It is important to realize that magnetization curves for ferromagnetic materials are all strongly dependant upon purity, heat treatment and other factors. However, two features of this curve are immediately apparent: it really is curved rather than straight and the vertical scale is now in teslas Figure MPB is a normal magnetization curve because it starts from an unmagnetized sample and shows how the flux density increases as the field strength is increased. These can be explained in terms of changes to the material's magnetic 'domains':

1. Close to the origin a slow rise due to 'reversible growth'.
2. A longer, fairly straight, stretch representing 'irreversible growth'.
3. A slower rise representing 'rotation'.
4. An almost flat region corresponding to paramagnetic behaviour and then μ_0 - the core can't handle any more flux growth and has saturated.

At an atomic level ferromagnetism is explained by a tendency for neighbouring atomic magnetic moments to become locked in parallel with their neighbours. This is only possible at temperatures below the Curie point, above which thermal disordering causes a sharp drop in permeability and degeneration into paramagnetism. Ferromagnetism is distinguished from paramagnetism by more than just permeability because it also has the important properties of remanence and coercivity.

Remnance occurs within ferromagnetic materials and is the flux density which remains in a magnetic material when any externally applied field is removed ($H = 0$). For materials used in permanent magnets we usually need a high value of remnance. For transformers we need low remnance.

Remnance is also what makes possible all magnetic recording technologies; including the hard disk drive on which this text was stored until you loaded it into your browser.

Coercivity occurs within ferromagnetic materials and is the field strength which must be applied in order to reduce (or *coerce*) a remnant flux to zero.

Materials with high coercivity (such as those used for permanent magnets) are sometimes called *hard*. A good example of a hard material is Alnico, which may have an H_c of about 80,000 A m^{-1}. Conversely, materials with low coercivity (such as those used for transformers) are called *soft*. Supermalloy has an H_c of about 0.5 A m^{-1}.

The materials with a low coercivity tend to have a high permeabilty and vice versa.

Energy loss per cycle is a heat loss caused by the magnetic properties of the armature. When an armature core is in a magnetic field, the magnetic particles of the core tend to line up with the magnetic field. When the armature core is rotating, its magnetic field keeps changing direction. The continuous movement of the magnetic particles, as they try to align themselves with the magnetic field, produces molecular friction. This, in turn, produces heat. This heat is transmitted to the armature windings. The heat causes armature resistances to increase.

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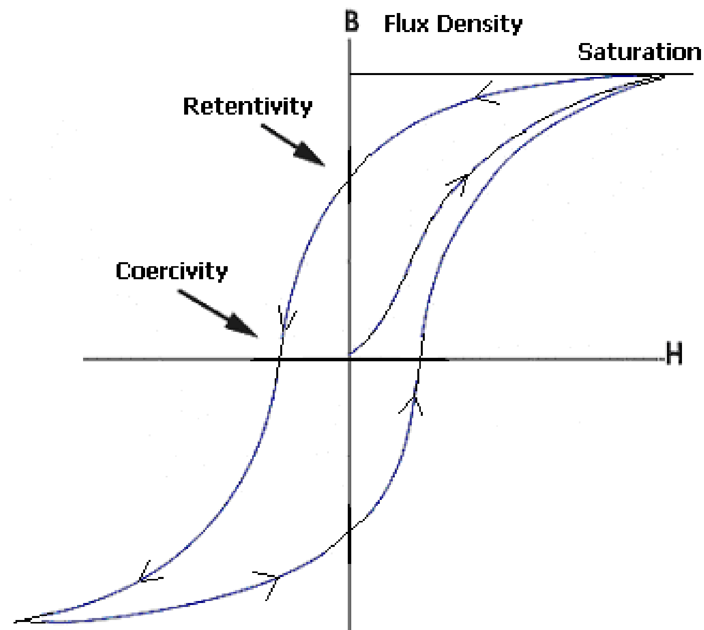
To compensate for these losses, heat-treated silicon steel laminations are used in most generator armatures. After the steel has been formed to the proper shape, the laminations are heated and allowed to cool. This annealing process reduces the loss per cycle to a low value.

Q.105 Draw the B-H curve for a ferro-magnetic material and identify the retentivity and the coercive field on the curve. What is the energy loss per cycle? How are ferrites superior to ferro-magnetic materials? **(4+2+3)**

Ans:



B-H curve for a ferromagnetic material is drawn above. Retentivity and Coercivity field are identified on the curve. Energy loss per cycle equals the area of the hysteresis loop and is dissipated as heat.
Ferrites have the inverse spinal structure and are important soft magnetic materials. With a higher manganese and magnesium ratio, the ferrites have nearly rectangular hysteresis loops and are used for memory cores in Computers.
Ferrites have higher resistance than the ferromagnetic materials. This makes them suitable for applications at higher frequencies – even micro-wave frequencies.

Q.106 Explain clearly the difference between hard and soft magnetic materials. Explain why Fe-Si alloys are used for power transformers whereas Ni-Fe alloys are used for pulse transformers. **(3+4)**

Ans: Hard magnetic materials
Permanent magnets are used as passive generators of magnetic field. To produce and maintain the magnetic field, a material should have both high residual induction and high coercivity. The minimum coercivity that a permanent magnet should have is at least of 50 000 A/m.

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The quality of a magnet has to be judged in relation to remnence Br, coercive force HcJ, HcB, maximum energy product BH_{max} and to physical characteristics such as temperature dependence, corrosion resistance, resistivity, brittleness, and, of course, the cost.
Examples: Alnico alloys, Ferrite, Samarium-Cobalt magnets, NdFeB, Bonded magnets etc.

<u>Applications of permanent magnets</u>

a - Applications based on attraction or repulsion forces

• Compass, magnetometers

• Holding devices

• Magnetic filtration

• Drives and couplings

• Switches

• Magnetic clutches

• Magnetic tools

b - Applications based on Faraday's induction law

• Generators

• Microphones

• Brakes

• Speedometers

c- Application based on Lorentz forces on conductors

• Loudspeakers

• DC motors

• Synchronous motors

• Brushless motors

• Hysteresis motors

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- Computer peripherals
- Measuring instruments
- Telephone receivers

d - Application based on Lorentz forces on single charges

- Travelling-wave tube
- Electron microscope
- Klystron
- Magnetron
- Mass spectrometer

Soft magnetic materials
Soft magnetic materials are mainly utilized in those applications in which the soft material has to amplify the flux generated by the electrical current or by a permanent magnet.
The principal characteristics of soft magnetic materials are remanence, coercivity, maximum and initial value of permeability and saturation value of B, H, J.
It is common to subdivide the soft magnetic materials in two categories, depending on the application: **DC applications** and **AC applications**.
Materials for DC applications
These applications generally require low coercivity Hc and high permeability.
The low value of coercivity is necessary to avoid remanence after the use, when the power switches off (for example in an electromagnet), and a high value of permeability is necessary to enhance the field H (being $B = \mu H$).
At the same time, it is also important to know the complete normal magnetization curve that describes the B induction value vs the value of H.

The most common DC applications are:

- Electromagnets and yokes
- Relays
- Magnetic shields
- Electrical measuring devices
- Magnetic amplifiers

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Materials used for DC applications are:

• Iron and low-carbon steels (maximum carbon 0.05 %)

• Iron-Nickel alloys (Permalloy)

• Iron-Cobalt alloy (Permendur)

Materials for AC applications

These applications generally require low coercivity Hc and low power loss, high permeability μ, high saturation magnetization.

The low value of power loss is necessary because in AC applications the material alternatively changes from one polarity to the other, so it is important to have a very thin hysteresis loop, with high saturation and consequently low coercivity (Hc).

Typical AC applications are:

• Transformers

• Motors and generators

• Signal transmitters and receivers

Materials used for DC applications are:

• Iron - Silicon alloys

• Iron - Nickel alloys (Permalloy)

• Soft ferrites

Fe-Si alloys are used for making power transformers because adding silicon helps in reducing the hysteresis loss and these alloys are suitable for operation at power frequencies whereas Fe-Ni alloys are suitable in communication equipment, where high sensitivity and fidelity are required so these are used in making pulse transformers where there is constant core saturation for a particular period and therefore we use Ni-Fe alloys for making them

Ferrites have higher resistance than the ferromagnetic material. This makes them suitable for application at high frequencies- even microwave frequencies.

Q.107 Explain the various steps required in the fabrication of an integrated circuit. What are the important functions of oxide layer in an integrated circuit? **(6+3)**

Ans: The fabrication of integrated circuits consists basically of the following process steps:

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- **Lithography:** The process for pattern definition by applying thin uniform layer of viscous liquid (photo-resist) on the wafer surface. The photo-resist is hardened by baking and than selectively removed by projection of light through a reticle containing mask formation.
- **Etching:** Selectively removing unwanted material from the surface of the wafer. The pattern of the photo-resist is transferred to the wafer by means of etching agents.
- **Deposition:** Films of the various materials are applied on the wafer. For this purpose mostly two kinds of processes are used, physical vapour deposition (PVD) and chemical vapour deposition (CVD).
- **Chemical Polishing:** A planarization technique by applying chemical slurry with etchant agents to the wafer surface.
- **Oxidation:** In the oxidation process oxygen (dry oxidation) or H_2O (wet oxidation) molecules convert silicon layers on top of the wafer to silicon dioxide.
- **Ion Implantation:** Most widely used technique to introduce dopant impurities into semiconductor. The ionized particles are accelerated through an electrical field and targeted at the semiconductor wafer.
- **Diffusion:** A diffusion step following ion implantation is used to anneal bombardment-induced lattice defects.

The functions of the oxide layer are to:

1. mask against diffusion or ion-implant
2. passivate the surface electrically and chemically
3. isolate one device from another
4. act as a component in MOS devices

Q.108 In the context of processing of electronic materials, explain oxidation, diffusion and metallisation. **(8)**

Ans: Oxidation: Oxidation is defined as the interaction between oxygen molecules and all the different substances they may contact, from metal to living tissue. Technically, however, with the discovery of electrons, oxidation came to be more precisely defined as the loss of at least one electron when two or more substances interact. Those substances may or may not include oxygen. (Incidentally, the opposite of oxidation is reduction — the addition of at least one electron when substances come into contact with each other.) Sometimes oxidation is not such a bad thing, as in the formation of super-durable anodized aluminum. Other times, oxidation can be destructive, such as the rusting of an automobile or the spoiling of fresh fruit.

We often used the words *oxidation* and *rust* interchangeably, but not all materials which interact with oxygen molecules actually disintegrate into rust. In the case of iron, the oxygen creates a slow burning process, which results in the brittle brown substance we call rust. When oxidation occurs in copper, on the other hand, the result is a greenish coating called copper oxide. The metal itself is not weakened by oxidation, but the surface develops a patina after years of exposure to air and water.

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When it involves oxygen, the process of oxidation depends on the amount of oxygen pre[illegible] in the air and the nature of the material it touches. True oxidation happens on a molecula[illegible] level — we only see the large-scale effects as the oxygen causes free radicals on the surface to break away. In the case of fresh fruit, the skin usually provides a barrier against oxidation. This is why most fruits and vegetables arrive in good condition at the grocery store. Once the skin has been broken, however, the individual cells come in direct contact with air and the oxygen molecules start burning them. The result is a form of rust we see as brownish spots or blemishes

Diffusion: Molecular diffusion, often called simply diffusion, is a net transport of molecules from a region of higher concentration to one of lower concentration by random molecular motion. The result of diffusion is a gradual mixing of material. In a phase with uniform temperature, absent external net forces acting on the particles, the diffusion process will eventually result in complete mixing or a state of equilibrium.

Molecular diffusion is typically described mathematically using two Fick's laws.

Applications of Diffusion is of fundamental importance in many disciplines of mechanical, electronics, chemistry, and biology. Some example applications of diffusion:

- Sintering to produce solid materials (powder metallurgy, production of ceramics)
- Chemical reactor design
- Catalyst design in chemical industry
- Steel can be diffused (e.g., with carbon or nitrogen) to modify its properties
- Doping during productions of semiconductors

Metallisation: metalizing is the process of evaporating a film of metal onto products. Normally the same is done in vacuum, thus called vacuum metalizing. The main advantages of vacuum metalising are finish, flexibility and price. Vacuum metalising allows for highly reflective, bright mirror finishes to be achieved, giving products a deep brilliant lustre. These affects can not be replicated by merely painting the parts. In fact the finish produced is almost identical to electroplating.However vacuum metalising has a number of advantages over electroplating. Unlike electroplating, that requires a specific plating grade of ABS to be used, vacuum metalising is far more versatile, successfully coating most types of plastic. Also, unlike electroplating it is possible to mask off mouldings, so that only specific areas are metalised. Again, unlike electroplating different colours and finishes can be achieved. Further to this vacuum metalising is also a cost effective alternative to traditional plating processes, offering a comparable quality of finish, yet providing considerable cost savings.

Q.109 Write notes on the following:-

(i) Properties of filament and contact materials.

(ii) Free electron theory of metals. **(8+8 = 16)**

Ans:

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(i) The Filament materials must have low resistance temperature co-efficients, high me[illegible] point, high mechanical strength, ductility and no tendency for oxidation. Therefore materia[illegible] like Carbon, Tantalum and Tungsten are most widely used for making the filaments.

Electrical contacts and contact materials are soft, high-conductivity, and oxidation-resistant materials that are used in circuit breakers, relays, switches, and electrical discharge machining (EDM) applications. They often have a second phase in order to provide anti-welding and/or arc resistance. Electrical contacts and contact materials are used in many different type of contacts. Battery contacts usually consist of a low-cost base metal that is plated with a layer of high-conductivity metal. Contact probes or spring contacts are brush assemblies with a plunger-style configuration and an internal helical spring. Electrical brushes are used in conjunction with slip rings and other contact surfaces to maintain an electrical connection in mobile or rotary applications. Furnace electrodes are used to heat and melt metals or ceramics in arc furnaces. Welding electrodes are designed for resistance, arc, or plasma welding. Special electrical contacts and contact materials are also commonly available. Electrical contacts and contact materials are available in many different forms. Examples include: contact tips or buttons, contact rivets, EDM drilling electrodes, electrode blocks or billets, pins or probes, solid rod stock, sockets or receptacles, small stampings, sheets or foils, strips or tapes, tamped connections, tapping electrodes, wires, and wheels. Contact tips and contact buttons consist of a shaped pad, often with nibs for welding or serrations for brazing. EDM drilling electrodes are solid-rod or hollow-tube electrodes used in drilling and trepanning applications. Electrode blocks and electrode billets are raw stock forms that are used to produce EDM electrodes or arc furnace electrodes. Pins and probes are used for testing printed circuit boards (PCB) or electronic components. Custom, application-specific and assembled electrical contacts and contact materials are also available. For contact materials, the factors which affect the choice of the material are contact resistance, contact force, voltage and current. So platinum, palladium, Silver, Gold, Tungsten, Molybdenum, Rhodium are used.

ii) Free Electron theory of metals

This theory tells that, metals conduct electricity because of the presence of free electrons in it. The outermost shells of metal atoms will be loosely bound with their nucleus. So the electrons in it are free to move anywhere in the solid. These electrons are called free electrons and they are responsible for the conduction of electricity. It can also be considered as a model of a metal in which the free electrons, that is, those giving rise to the conductivity, are regarded as moving in a potential (due to the metal ions in the lattice and to all the remaining free electrons) which is approximated as constant everywhere inside the metal. Also known as Sommerfeld model.

Sommerfeld theory: The theory was originally proposed in 1900 to describe and correlate the electrical and thermal properties of metals. Later, quantum mechanics became the basis for the theory of most of the general properties of simple metals such as sodium, with one free

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electron per atom, magnesium with two, and aluminum with three. Transition metals, suc iron, have partially filled electronic *d* states and are not treated by the free-electron model.

Q.110 What is density of energy states? Draw a plot between density of states and the energy of electrons. Explain why nichrome is used as a heating element instead of copper. **(2+2+4)**

Ans: The density of states (DOS) of a system describes the number of states at each energy level that are available to be occupied. A high DOS at a specific energy level means that there are many states available for occupation. A DOS of zero means that no states can be occupied at that energy level.

Waves, or wave-like particles, can only exist within quantum mechanical (QM) systems if the properties of the system allow the wave to exist. In some systems, the inter-atomic spacing and the atomic charge of the material allows only electrons of certain wavelengths to exist. In other systems, the crystalline structure of the material allows waves to propagate in one direction, while suppressing wave propagation in another direction. Waves in a QM system have specific wavelengths and can propagate in specific directions, and each wave occupies a different mode, or state. Because many of these states have the same wavelength, and therefore share the same energy, there may be many states available at certain energy levels, while no states are available at other energy levels. For electrons at the conduction band edge, very few states are available for the electron to occupy. As the electron increases in energy, the electron density of states increases and more states become available for occupation. However, because there are no states available for electrons to occupy within the band gap, electrons at the conduction band edge must lose at least E_g of energy in order to transition to another available mode. The density of states can be calculated for electron, photon, or phonon in QM systems. The DOS is usually represented by one of the symbols $g, \rho, D, n,$ or $N,$ and can be given as a function of either energy or wave vector k. To convert between energy and wave vector, the specific relation between E and k must be known. For example, the formula for electrons is

$$E = \frac{(\hbar k)^2}{2m}$$

And for photons, the formula is

$$E = \hbar c k$$

Nichrome is used as a heating element instead of copper, due to its relatively high resistivity and resistance to oxidation at high temperatures.

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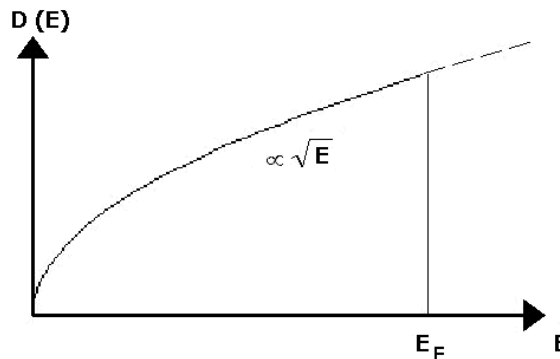

Plot between density of states and the energy of electrons.

Q.111 Explain the different types of polarization mechanisms in dielectrics. What is complex dielectric constant? How does it vary with frequency of the applied field? Explain local electric field. **(3+2+3+2)**

Ans: There are essentially **four basic kinds of polarization mechanisms**:

Interface polarization:

Surfaces, grain boundaries, interphase boundaries (including the surface of precipitates) may be charged, i.e. they contain dipoles which may become oriented to some degree in an external field and thus contribute to the polarization of the material.

Electronic polarization:

Also called atom or atomic polarization. An electrical field will always displace the center of charge of the electrons with respect to the nucleus and thus induce a dipole moment. The paradigmatic materials for the simple case of atoms with a spherical symmetry are the noble gases in all aggregate forms.

Ionic polarization.

In this case a (solid) material must have some ionic character. It then automatically has internal dipoles, but these built-in dipoles exactly cancel each other and are unable to rotate. The external field then induces net dipoles by slightly displacing the ions from their rest position. The paradigmatic materials are all simple ionic crystals like NaCl.

Orientation polarization.

Here the (usually liquid or gaseous) material must have natural dipoles which can rotate freely. In thermal equilibrium, the dipoles will be randomly oriented and thus carry no net polarization. The external field aligns these dipoles to some extent and thus induces a polarization of the material. The paradigmatic material is water, i.e. H_2O in its liquid form.

Some or all of these mechanisms may act simultaneously. Atomic polarization, e.g., is always present in any material and thus becomes superimposed on whatever other mechanism there might be.

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The **complex dielectric constant** can be defined as the vectorial sum of the dielectric cons... and the loss factor in unity dimensions analagous to complex shear modulus and to comple... Young's modulus:

$\varepsilon^* = \varepsilon' - i\varepsilon''$

where

ε' = real part of the dielectric constant

ε'' = imaginary part; loss factor

Electronic Polarization is very rapid and occurs at all frequencies even in the optical range (~10^{15} Hz). Ionic Polarization is slower than electronic polarization and if an electric field of frequency in the optical range is now applied, the ions don't respond at all. So at optical frequencies there is no ionic polarization. Orientation Polarization is even slower than the ionic polarization and Orientation polarization occurs, when the frequency of the applied voltage is in the audio range. And the Space charge polarization occurs at machine frequencies only (50-60 Hz). The electric field produced during the polarization or the effected and modified final electric field is often termed as the local electric field.

Oil filled transformers with conservators (an oil tank above the transformer) tend to be equipped with Buchholz relays. These are safety devices that can sense gas buildup inside the transformer (a side effect of corona or an electric arc inside the windings) and then switch off the transformer. Transformers without conservators are usually equipped with sudden pressure relays, which perform a similar function as the Buchholz relay.

Q.112 In what important respect does the conductivity of a conductor differ from that of an intrinsic semiconductor. **(5)**

Ans: It is well known that the conductivity of a conductor is much higher than that of the intrinsic semi-conductor. In an intrinsic semiconductor the number of electrons in the conduction band is equal to the number of holes in the valence band at room temperature and there exists an Energy Gap between the conduction band and valence band which doesn't allow charge carriers to move freely and thus their conductivity is low.

A conductor such as a metal has high conductivity. The conductivity of a semiconductor is generally intermediate, but varies widely under different conditions, such as exposure of the material to electric fields or specific frequencies of light, and, most important, with temperature and composition of the semiconductor material.

Electrical conductivity is strongly dependent on temperature. In semiconductors, electrical conductivity increases with increasing temperature.

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