

**Model Answer: AS-2125 (Materials Science – I)**

**Section-A**

**(10 × 2 =20)**

- i. Which of the following is not a condition of Hume – Rothery solid solubility rules
- The elements should not have same valance
  - The crystal structure of each element of the solid solution must be the same
  - The size of the atoms of each of the two elements must not differ by more than 15 percent
  - The elements should not form compounds with each other

Ans: **a**

- ii. Which of the following is correct for the activation energy for diffusion , Q
- $Q_{\text{surface}} < Q_{\text{lattice}} < Q_{\text{grain boundary}}$
  - $Q_{\text{grain boundary}} < Q_{\text{lattice}} < Q_{\text{surface}}$
  - $Q_{\text{lattice}} < Q_{\text{surface}} < Q_{\text{grain boundary}}$
  - $Q_{\text{surface}} < Q_{\text{grain boundary}} < Q_{\text{lattice}}$

Ans: **d**

- iii. For a spherical particle of radius r, the surface to volume ratio is
- 3/r
  - r/3
  - 3r
  - $\pi r/3$

Ans: **a**

- iv. The crystal structure of  $\alpha$  – ferrite and  $\gamma$  - ferrite, respectively are
- BCC and FCC
  - FCC and BCC
  - BCC and BCC
  - FCC and FCC

Ans: **a**

- v. During solid state sintering
- Porosity decreases
  - Reaction occurs and new phase emerges
  - Impurities go away
  - Both a & b

Ans: **d**

- vi. Which of the following works in transition flow regime of gases
- a. Rotary pump   b. Diffusion pump   c. Turbo Molecular pump   d. Cryopump

Ans: **a**

- vii. The weight in amu of a polyethelene chain with 1000 mers is
- a. 28,000      b. 280,000      c. 62,000      d. 42,000

Ans: **a**

- viii. The polymeric chains in fibre are
- a. Randomly oriented
- b. More or less alinged in the long direction of the fibre
- c. Both a&b
- d. None of these

Ans: **b**

- ix. The net mangnetic moment in a spinel with formula  $\text{Fe}_a^{3+}\text{Fe}_b^{+3}\text{M}_b^{+2}\text{O}_4$  (Where magnetic moment of M is  $4\mu_B$ )

- a.  $4\mu_B$    b.  $9\mu_B$       c.  $5\mu_B$       d.  $14\mu_B$

Ans: **a**

- x. For materials having ferromagnetism
- a.  $\mu_r > 1$  but close to 1      b.  $\mu_r = 1$       c.  $\mu_r < 1$  but close to 1
- d.  $\mu_r > 1$  but very large

Ans: **d**

**Note:** Answer any **five** questions. Each question carries 8 marks.

2. Define solid solubility and write a note on binary isomorphous phase diagram with an example. Discuss about the Lever rule and explain about the deduction of weight fractions of in the mixed phases.

Answer:

**Solid solubility:**

A solid solution forms when, as the solute atoms are added to the host material, the crystal structure is maintained, and no new structures are formed. A solid solution is also compositionally homogeneous; the impurity atoms are randomly and uniformly dispersed within the solid. The degree to which the solute dissolves in the solvent is

determined by various factors like atomic size, crystal structure of both atoms, electronegativity and valences. For many alloys systems and at some specific temperature there is a maximum concentration of solute atoms that may dissolve in the solvent to form a solid solution this is called a solubility limit. The addition of solute in excess of this solubility limit results in the formation of another solid solution or compound that has a distinctly different composition.

### Binary isomorphous phase diagram:

Equilibrium phase diagrams represents the relations between temperature and the compositions and the quantities of phases at equilibrium. A binary alloy is one that contains two components. The simplest binary phase diagram is obtained for a system exhibiting complete liquid solubility as well as solid solubility i.e., the two components dissolve in each other in all proportions both in liquid and solid states. The phase diagram of such a system is called binary isomorphous phase diagram.

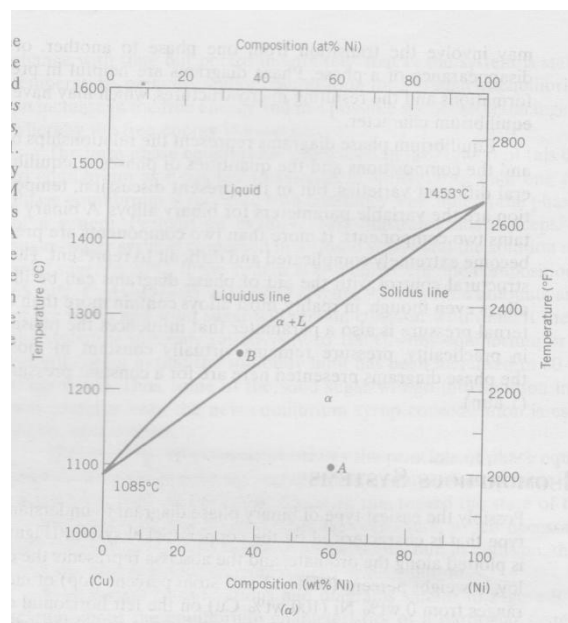


Fig.1. Copper – Nickel (Cu – Ni) phase diagram

Copper - Nickel system is an example of such a phase diagram. The phase diagram (Fig.1.) shows three different phase regions appear on the diagram, an alpha ( $\alpha$ ), a liquid (L), and a two phase ( $\alpha+L$ ) region, as shown in the Fig.1. The liquid and alpha phases consist both copper and nickel and are completely soluble for all compositions.

### Lever rule:

The relative amounts of the phases present at equilibrium can be computed with the help of phase diagrams. If the composition and temperature where the phase analysis is to be done is located within a two phase region (mixed region) then the phase analysis can be done with the help of lever rule as explained below,

1. The tie is constructed across the mixed phase region at the temperature of alloy (horizontal isothermal line).
2. The overall alloy composition is located by the perpendicular drawn onto the composition axis from the point on the tie line.
3. The fraction of one phase is computed by taking the length of tie line from the overall alloy composition to the phase boundary for the other phase and dividing by the total tie line length.
4. The fraction of the other phase is determined in the same manner.
5. If phase percentages are desired, each phase fraction is multiplied by 100. When the composition axis is scaled in weight percent, the phase fractions computed using the lever rule are mass fractions - the mass (or weight) of a specific weight divided by the total alloy mass (weight). The mass of each phase is computed from product of each phase fraction and the total alloy mass.

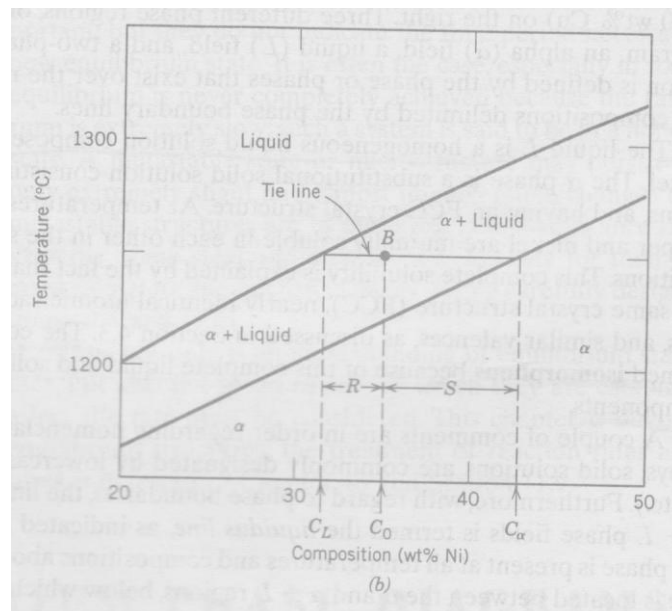


Fig.2 A portion of Cu – Ni phase diagram for which composition and phase amounts are determined at B

In the employment of the lever rule, tie line segment lengths are determined either by direct measurement from the phase diagram using a linear scale, preferably in millimeters, or by subtracting compositions as taken from the composition axis.

As an example (Fig.2.), if the overall composition be located at  $C_0$ , the perpendicular from the intersection of the tie line with the liquidus boundary meets the composition axis at  $C_L$ , like-wise for solidus – tie line intersection the composition is  $C_\alpha$  and mass fractions represented by  $W_L$  and  $W_\alpha$  for the respective phases. From the lever rule  $W_L$  is computed as given below.

$$W_L = C_\alpha - C_0 / C_\alpha - C_L$$

Similarity for the  $\alpha$  phase,  $W_\alpha = C_0 - C_\alpha / C_\alpha - C_L$

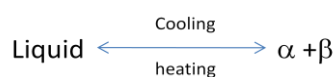
Thus, the lever rule may be employed to determine the relative amounts or fractions of phases in any two – phase region for a binary alloy if the temperature and composition are known and if equilibrium has been established.

3. Define invariant reactions in phase transformation and explain at least two invariant reactions. Explain the Pb – Sn phase diagram by giving all invariant reaction present in the phase diagram.

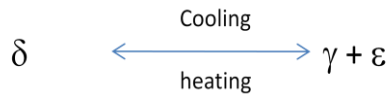
**Answer:**

Many pairs of elements and compounds are unlikely to satisfy the conditions for complete solid solubility. Solid solubility is therefore limited in a number of binary systems, but it is never zero. In such situations the phase diagrams consist few points where the degrees of freedom becomes zero. Such points in phase diagram are called invariant points and the phase transition reaction is called invariant reaction. Two examples, Eutectic and Eutectoid reactions are explained below.

- i. Eutectic reaction: Upon cooling if a liquid phase transforms into a mixture of two solid phases ( $\alpha$  and  $\beta$ ) and vice versa then such a reaction in the phase transition is called Eutectic reaction



- ii. Eutectoid reaction: Upon cooling if a solid phase ( $\delta$ ) transforms into two other solid phases ( $\gamma$  and  $\epsilon$ ) and the reverse reaction occurs upon heating, then such a reaction is called Eutectoid reaction.



**Pb – Sn phase diagram:**

Fig.3 shows Pb- Sn (lead – tin system) phase diagram. The phase diagram consists a complete liquid solubility, the liquid phase extends over all compositions above the melting temperatures of the components. The solid phase at the left end is the lead rich  $\alpha$  phase which dissolves only a limited amount of tin. This solubility decreases with decreasing temperature. This limit of solid solubility is indicated by the phase boundary between  $\alpha$  and  $\alpha+\beta$ , called solvus line. The solid solution phase at the right end is the tin – rich  $\beta$  phase, with only a very small quantity of lead dissolved in it.

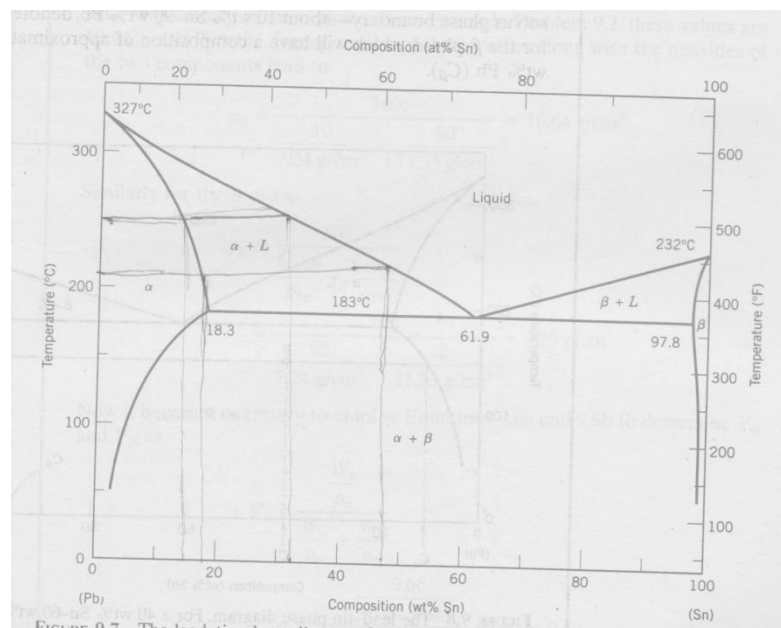
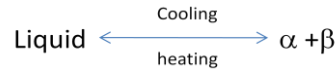


Fig.3. The lead – tin phase diagram

The phase boundaries on this diagram are as follows:

- Liquidus I: boundary between L and L +  $\alpha$  regions
- Liquidus II: boundary between L and L +  $\beta$  regions
- Solidus I: boundary between  $\alpha$  and L+  $\alpha$  regions
- Solidus II: boundary between  $\alpha$  and L+  $\beta$  regions
- Solvus I: boundary between  $\alpha$  and  $\alpha+\beta$  regions
- Solvus II: boundary between  $\beta$  and  $\alpha+\beta$  regions

The three two phase regions are separated by a horizontal line corresponding to the temperature  $T_e$  called the eutectic temperature. Below the eutectic temperature, the material is solid for all compositions. The composition which remains fully liquid upto the eutectic temperature during cooling is called the eutectic composition  $C_e$ . At the eutectic temperature the following eutectic reaction takes place:



Summarizing eutectic characteristics of the Pb – Sn system,

eutectic temperature  $T_e = 183^{\circ}\text{C}$

Composition of liquid = 62% Sn

Composition of  $\alpha = 18\%$  Sn

Composition of  $\beta = 97\%$

4. Discuss the geometry of substrate and source in the evaporation chamber and its effect on the thickness uniformity of the thin film prepared by evaporation technique.

Answer:

Deposition geometry: Deposition of thin films involves consideration of both the source of evaporant atoms and the substrates upon which they impinge. Source – substrate geometry plays a vital role in controlling film thickness uniformity. Evaporation from a point source is a simple model to understand the evaporation rate and its distribution. In this case, evaporant particles are imagined to originate from an infinitesimally small region ( $dA_e$ ) of a spherical source of surface area  $A_e$  with a uniform mass evaporation rate as shown Fig.4. The total evaporated mass  $M_e$  is then given by the double integral

$$M_e = \int_0^t \int_{A_e} \Gamma_e dA_e dt$$

Of this amount, mass  $dM_s$  falls on the surface of area  $dA_s$ . Since the projected area  $dA_s$  on the surface of the sphere is  $dA_c$ , with  $dA_c = dA_s \cos\theta$ , the proportionality holds that  $dM_s:M_e = dA_c:4\pi r^2$ . Finally,

$$\frac{dM_s}{dA_s} = \frac{M_e \cos\theta}{4\pi r^2}$$

is obtained where  $\theta$  is the angle between the vector from the origin to the planar substrate and the vector representing the substrate normal. Knudsen cells are frequently employed

in molecular beam epitaxy deposition systems where precise control of evaporation variables is required. Kinetic theory predicts that the molecular flow of the vapor through the hole is directed according to a cosine distribution law and this has been verified experimentally. The mass deposited per unit area is then given by

$$\frac{dM_s}{dA_s} = \frac{M_e \cos\theta \cos\phi}{\pi r^2}$$

and is now dependent on two angles that are defined in Fig.5 These correspond to the evaporant emission angle  $\phi$  and the the deposition or receiving angle  $\theta$ .

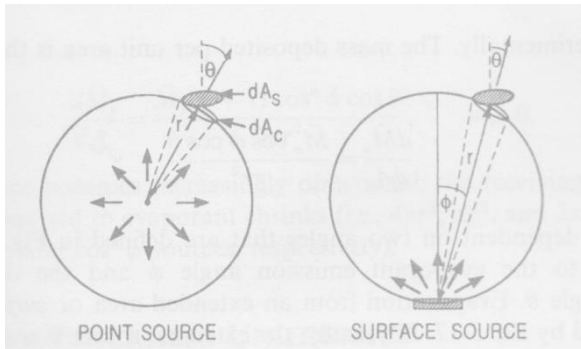


Fig.4. Evaporation geometry for point and surface source

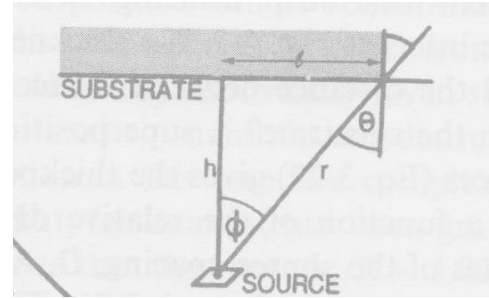


Fig.5. Geometry of evaporation onto parallel plane surface

Maintaining thin film thickness uniformity is always desirable and it is essential for microelectronic and many optical coating applications. Consider evaporation from point and surface sources onto a parallel plane receiving substrate surface as indicated in the Fig.5. The thin film thickness  $d$  is given by  $dM_s/\rho dA_s$  where  $\rho$  is the density of the deposit. For the point source

$$d = \frac{M_e \cos\theta}{4\pi r^2} = \frac{M_e h}{4\pi r^3} = \frac{M_e h}{4\pi \rho (h^2 + l^2)^{3/2}}$$

after noting that  $r = (h^2 + l^2)^{1/2}$ .

The thickest deposit ( $d_0$ ) occurs at  $l = 0$  in which case  $d_0 = M_e/4\pi\rho h^2$  and thus,

$$\frac{d}{d_0} = \frac{1}{\left\{1 + \left(\frac{l}{h}\right)^2\right\}^{3/2}}$$

Similarly, for the surface source

$$d = \frac{M_e \cos\theta \cos\phi}{\pi r^2} = \frac{M_e h h}{\pi r^2 r r} = \frac{M_e h^2}{\pi \rho (h^2 + l^2)^2}$$



Since  $\cos\theta = \cos\phi = h/r$ . When normalized to the thickest dimensions  $d_0 = M_e/\pi\rho h^2$ ,

$$\frac{d}{d_0} = \frac{1}{\left\{1 + \left(\frac{l}{h}\right)^2\right\}^2}$$

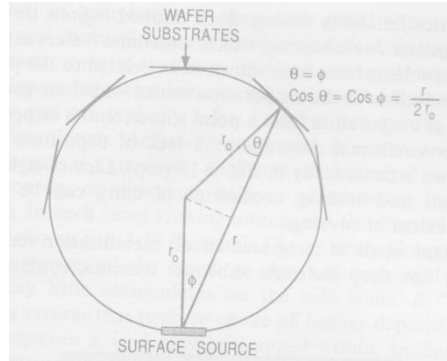


Fig.6. Evaporation scheme to achieve uniform deposition. Source and substrate lie on sphere surface of radius  $r_0$ .

A clever way to achieve thickness uniformity is to locate both the surface evaporant source and the substrate on the surface of a sphere as shown in Fig.6. In this case the isosceles triangle defining the deposition geometry means that  $\theta = \phi$ , and  $\cos\theta = \cos\phi = r/2r_0$ . Therefore equation becomes

$$\frac{dM_s}{dA_s} = \frac{M_e}{\pi r^2} \frac{r}{2r_0} \frac{r}{2r_0} = \frac{M_e}{4\pi r_0^2}$$

The resultant deposit thickness is a constant clearly independent of angle.

5. Define number average and weight average molecular weight for a polymer. The number average molecular weight of a polypropylene is 1,000,000 g/mol. Compute the number – average degree of polymerization.

Answer:

Extremely large molecular weights are to be found in polymers with very long chains. During the polymerization process in which these large macromolecules are synthesized from smaller molecules not all polymer chains will grow to the same length; this results in distribution of chain lengths or molecular weights. Ordinarily, an average molecular weight is specified, which may be determined by the measurement of various physical properties such as viscosity and osmotic pressure.

There are several ways of defining average molecular weight. The number of average molecular weight  $M_n$  is obtained by dividing the chains into a series of size ranges and

then determining the number fraction of chains within each size range. This number-average molecular weight is expressed as

$$M_n = \sum x_i M_i$$

where  $M_i$  represents the mean molecular weight of size range  $i$ , and  $x_i$  is the fraction of the total number of chains within the corresponding size range.

A weight average molecular weight  $M_w$  is based on the weight fraction of molecules within the various size ranges. It is calculated according to

$$M_w = \sum w_i M_i$$

where  $M_i$  represents the mean molecular weight of size range  $i$ , and  $w_i$  is the weight fraction of the molecules within the same size interval.

An alternate way of expressing average chain size of a polymer is as the degree of polymerization,  $n$ , which represents the average number of mer units in a chain.

Solution to numerical:

The mer molecular weight of polypropylene is

$$\begin{aligned} m &= 3(\text{AC}) + 6(\text{AH}) \\ &= (3)(12.01 \text{ g/mol}) + (6)(1.008 \text{ g/mol}) = 42.08 \text{ g/mol} \end{aligned}$$

If we let  $n_n$  represent the number-average degree of polymerization,

$$\begin{aligned} n_n &= M_n / m \\ &= 10^6 / 42.08 = 23,700 \end{aligned}$$

6. (A) Explain the method of synthesis of magnetic bubbles and discuss their usability in magnetic bubble memory technology.
- (B) Write a note on the microwave applications of ferrite materials.

Answer:

**(A) magnetic bubble memory description**

Small cylindrical magnetic domains, which are called magnetic bubbles, can be formed in single - crystal thin films of synthetic ferrites or garnets when an external magnetic field is applied perpendicularly to the surface of the film. These bubbles can be moved laterally through the film by using a varying magnetic field. These characteristics of magnetic bubbles make them ideally suited for serial storage of data

bits; the presence or absence of a bubble in a bit position is used to define the logic state. Since the diameter of a bubble is so small (as little as a tenth of a micrometer), many thousands of data bits can be stored in a single bubble-memory chip. The chip is composed of a nonmagnetic crystalline substrate upon which a thin crystalline magnetic epitaxial film is grown. The bubbles are highly mobile and are stable over a fairly wide range of temperatures. The material chosen for the substrate depends on several factors. The crystalline structure should be compatible with that of the magnetic film, it should have nearly the same coefficient of expansion, and it should be nonmagnetic. The most-used garnet substrate with these properties is gadolinium gallium garnet (GGG). The magnetic film grown on this substrate has a crystalline structure that will allow the formation of magnetic domains (bubbles) in a plane perpendicular to the substrate.



Fig.7. Magnetic bubble domains

Without the influence of an external magnetic field, these magnetic domains form random serpentine patterns of equal area, minimizing the total magnetic energy of the magnetic film (Fig. 7). The magnetic field of the serpentine domains tends to line up primarily along a single axis (the "easy" axis) that is perpendicular to the plane of the film. If an external magnetic field is applied, its energy tends to expand domains polarized in the direction of the field and to shrink those polarized opposite to the field until they become small cylinders embedded in a background of opposite magnetization. Viewed on end, these cylinders have the appearance of small circles or bubbles with diameters from 2 to 30 micrometers. Increasing the field further causes the bubble to collapse or to be "annihilated". The external field provides a bias that makes the bubbles stable. This bias, being a static field, can be readily provided by permanent magnets with no expenditure of power.

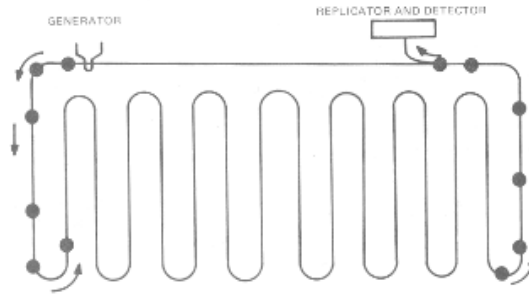


Fig.8. Architecture using a single loop

One possible implementation for the magnetic bubble memory is a long shift register. As shown in Figure 8 the bubbles would shift under the influence of the rotating magnetic field following the path determined by the placement of chevron patterns. Even though this approach offers the simplest design and interface control, it suffers a major disadvantage of having the slowest access time. The reason for this is that after a data bit is entered or written it must circulate through the entire shift register before it can be retrieved or read. Another problem with this single loop design is that a single fault in the shift register structure produces a defective bubble memory chip. This results in a low processing yield and a high cost to the consumer.

#### (B) Microwave applications of Ferrites

There has been an increasing demand of magnetic materials for high-frequency applications such as telecommunications and radar systems, as microwave technology requires higher frequencies and bandwidths up to 100 GHz. Ferrites are non conducting oxides and therefore allow total penetration of electromagnetic fields, in contrast with metals, where the skin effect severely limits the penetration of high-frequency fields. At such frequencies, domain walls are unable to follow the fields (dispersion of domain walls typically occurs about 10GHz), and absorption of microwave power takes place by spin dynamics. The usual geometry is to align spins first with a DC magnetic field  $H$  and apply the microwave field perpendicular to  $H$ . The spins precess around their equilibrium orientation at the frequency of the microwave field. Ferromagnetic resonance (FMR) is associated with the uniform (in phase) precession of spins. The upper limit of applications of ferrites is FMR, since the interaction with the microwave field becomes negligible as  $\omega > \omega_0$  (FMR frequency). Spinels are therefore applied at frequencies up to 30 GHz, while this limit is about 10 GHz for garnets and can attain 100 GHz for hexaferrites. The absorption of microwaves by ferrites involves losses.. In polycrystalline ferrites, losses are

associated with defects and the anisotropy field distribution, and with electrical conduction a common problem, especially in spinels, is the presence of Fe<sup>2+</sup>, which promotes a hopping conduction process in combination with Fe<sup>3+</sup>. Some of ferrite applications rely on the fact that the spin rotation depends on the orientation of the external field, which allows the control of the interaction with the microwave field. For one direction of the field, the ferrite transmits the microwave field; for the opposite, it strongly absorbs it. This is the basis of nonreciprocal devices. Typical devices are circulators, isolators, phase shifters, and antennas. Circulators were developed for radar systems and are now used in mobile phones. Circulators are usually fabricated with garnets.

7. Explain electrode potential and electrochemical series. From electrochemical series how you differentiate between noble and active elements.

Answer:

Electrode potentials: For metallic materials, the corrosion process is normally electrochemical, that is, a chemical reaction in which there is transfer of electrons from one chemical species to another. Not all metallic materials oxidize to form ions with the same degree of ease. In an electrochemical cell shown in Fig.9, on the left-hand side is a piece of pure iron immersed in a solution containing Fe<sup>2+</sup> ions of 1M concentration and the other side of cell consists of a pure copper electrode in a 1M solution of Cu<sup>2+</sup> ions. The cell halves are separated by a membrane, which limits the mixing of the two solutions. If the iron copper electrodes are connected electrically, reduction will occur for copper at the expense of the oxidation of iron, as follows:

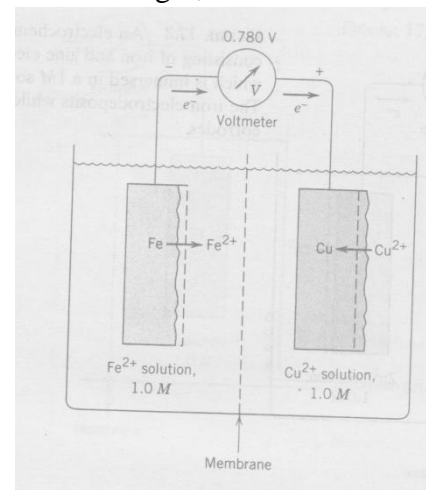


Fig.9. An electrochemical cell consisting Fe and Cu electrodes



or Cu<sup>2+</sup> ions will deposit (electrodeposit) as metallic copper on the copper electrode, while iron dissolves (corrodes) on the other side of the cell and goes into solution as Fe<sup>2+</sup> ions. Thus, the two-half cell reactions are represented by the relations.





when a current passes through the external circuit, electrons generated from the oxidation of iron flow to the copper cell in order that  $\text{Cu}^{2+}$  be reduced. In addition, there will be some net ion motion from each cell to the other across the membrane. This is called a galvanic couple – two metals electrically connected in a liquid electrolyte wherein one metal becomes an anode and corrodes, while the other acts as a cathode.

An electric potential or voltage will exist between the two cell halves, and its magnitude can be determined if a voltmeter is connected in the external circuit. A potential of 0.78 V results for a copper – iron galvanic cell when the temperature is  $25^{\circ}\text{C}$ .

Thus, various electrode pairs have different voltages; the magnitude of such a voltage may be thought of as representing the driving force for the electrochemical oxidation-reduction reaction. Consequently, metallic materials may be rated as to their tendency to experience oxidation when coupled to other metals in solutions of their respective ions. A half-cell similar to those described above [i.e., a pure metal electrode immersed in a 1M solution of its ions and at  $25^{\circ}\text{C}$ ] is termed a standard half-cell.

The standard emf series

These measured cell voltages represent only differences in electrical potential and thus it is convenient to establish a reference point, or reference cell, to which other cell halves may be compared. This reference cell, arbitrarily chosen, is the standard hydrogen electrode. It consists of an inert platinum electrode in a 1M solution of  $\text{H}^{+}$  ions, saturated with hydrogen gas that is bubbled through the solution at a pressure of 1 atm and a temperature of  $25^{\circ}\text{C}$ . The platinum itself does not take part in the electrochemical reaction; it acts only as a surface on which hydrogen atoms may be oxidized or hydrogen ions may be reduced. The electromotive force (emf) series is generated by coupling to the standard hydrogen electrode, standard half-cells for various metals and ranking them according to measured voltage.

Represents the corrosion tendencies for the several metals; those at top (i.e., gold and platinum) are noble, or chemically inert. Moving down the table, the metals become increasingly more active, that is, more susceptible to oxidation. Sodium and potassium have the highest reactivities.

The voltages in table are for the half-reactions as reduction reactions, with the electrons on the left-hand side of the chemical equation; for oxidation, the direction of the reaction is reversed and the sign of the voltage changed.

Consider the generalized reactions involving the oxidation of metal M1 and the reduction of metal m2 as



where the  $V^0$ 's are the standard potentials as taken from the standard emf series. Since metal  $M_1$  is oxidized, the sign of  $V_1$  is opposite to that as it appears in Table.1. Addition of equations yields



and the overall cell potential

$$\Delta V^0 = V_2^0 - V_1^0 \quad (8)$$

For this reaction to occur spontaneously,  $\Delta V^0$  must be positive; if it is negative, the spontaneous cell direction is just the reverse of eq. 7. When standard half-cells are coupled together, the metal that lies lower in table will experience oxidation (i.e., corrosion), whereas the higher one will be reduced.

**Table.1: Standard Electrochemical series**

	<i>Electrode Reaction</i>	<i>Standard Electrode Potential, <math>V^0</math>(V)</i>
	$Au^{3+} + 3e^- \rightarrow Au$	+1.420
	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	+1.229
	$Pt^{2+} + 2e^- \rightarrow Pt$	~+1.2
	$Ag^+ + e^- \rightarrow Ag$	+0.800
	$Fe^{3+} + e^- \rightarrow Fe^{2+}$	+0.771
	$O_2 + 2H_2O + 4e^- \rightarrow 4(OH^-)$	+0.401
	$Cu^{2+} + 2e^- \rightarrow Cu$	+0.340
	$2H^+ + 2e^- \rightarrow H_2$	0.000
	$Pb^{2+} + 2e^- \rightarrow Pb$	-0.126
	$Sn^{2+} + 2e^- \rightarrow Sn$	-0.136
	$Ni^{2+} + 2e^- \rightarrow Ni$	-0.250
	$Co^{2+} + 2e^- \rightarrow Co$	-0.277
	$Cd^{2+} + 2e^- \rightarrow Cd$	-0.403
	$Fe^{2+} + 2e^- \rightarrow Fe$	-0.440
	$Cr^{3+} + 3e^- \rightarrow Cr$	-0.744
	$Zn^{2+} + 2e^- \rightarrow Zn$	-0.763
	$Al^{3+} + 3e^- \rightarrow Al$	-1.662
	$Mg^{2+} + 2e^- \rightarrow Mg$	-2.363
	$Na^+ + e^- \rightarrow Na$	-2.714
	$K^+ + e^- \rightarrow K$	-2.924

↑  
Increasingly inert  
(cathodic)

↓  
Increasingly active  
(anodic)

8. Explain galvanic corrosion. Discuss the importance of Galvanic series. Distinguish between electrochemical and Galvanic series

Galvanic corrosion:

Galvanic corrosion occurs when two or more alloys having different compositions are electrically coupled while exposed to an electrolyte. The less noble or more reactive metal in the particular environment will experience corrosion; the more inert metal, the cathode, will be protected from corrosion. For example, steel screws corrode when in contact with brass in a marine environment; or if copper and steel tubing are joined in a domestic water heater, the steel will corrode in the vicinity of the junction. Depending on the nature of the solution, one or more of the reduction reactions, equations through, will occur at the surface of the cathode material shows galvanic corrosion.

The rate of galvanic attack depends on the relative anode-to-cathode surface areas that are exposed to the electrolyte, and the rate is related directly to the cathode-anode area ratio; that is, for a given cathode area, a smaller anode will corrode more rapidly than a longer one. The reason for this is that corrosion rate depends on current density, the current per unit area of corroding surface, and not simply the current. Thus, a high current density results for the anode when its area is small relative to that of the cathode.

A number of measures may be taken to significantly reduce the effects of galvanic corrosion. These include the following:

1. If coupling of dissimilar metals is necessary, choose two that are close together in the galvanic series.
2. Avoid unfavorable anode-to-cathode surface area ratio: use an anode area as large as possible.
3. Electrically insulate dissimilar metals from each other.
4. Electrically connect a third, anodic metal to the other two; this is a form of cathodic protection, discussed presently.

The Galvanic series:

The galvanic series, given in Table 2, indicates the relative reactivities, in seawater, of a number of metals and alloy. When two alloys are coupled in sea water, the one lower in the series will experience corrosion. Some of the alloys in the table are



grouped in brackets. Generally the base metal is the same for these bracketed alloys, and there is little danger of corrosion if alloys within a single bracket are coupled. It is also worth noting from this that some alloys are listed twice (e.g., nickel and the stainless steels), in both active and passive states. The alloys near the top are cathodic and unreactive, whereas at the bottom are most anodic no voltages are provided. Comparison of the standard emf and the galvanic series reveals a high degree of correspondence between the relative positions of the pure base metals.

Table:2. The Galvanic series

	Platinum
	Gold
	Graphite
	Titanium
	Silver
	[316 Stainless steel (passive)
	[304 Stainless steel (passive)
	[Inconel (80Ni-13Cr-7Fe) (passive)
	Nickel (passive)
	Monel (70Ni-30Cu)
	Copper-nickel alloys
	Bronzes (Cu-Sn alloys)
	Copper
	Brasses (Cu-Zn alloys)
	Inconel (active)
	Nickel (active)
	Tin
	Lead
	[316 Stainless steel (active)
	[304 Stainless steel (active)
	[Cast iron
	[Iron and steel
	Aluminum alloys
	Cadmium
	Commercially pure aluminum
	Zinc
	Magnesium and magnesium alloys

Increasingly inert (cathodic) ↑

↓ Increasingly active (anodic)

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Most metals and alloys are subject to oxidation or corrosion to one degree or another in a wide variety of environments; that is, they are stable in an ionic state than as metals. In thermodynamic terms, there is a net decrease in free energy in going from metallic to oxidized states. Consequently, essentially all metals occur in nature as compounds—for example, oxides, hydroxides, carbonates, silicates, sulfides, and sulfates. Two notable exceptions are the noble metals gold and platinum. For them, oxidation in most environments is not favorable and therefore, they may exist in nature in the metallic state.

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