JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY
HYDERABAD

I Year B.Tech.

L T/P/D C

2 1/-/- 4

ENGINEERING PHYSICS

UNIT-I

1. Bonding in Solids: Ionic Bond, Covalent Bond, Metallic Bond, Hydrogen Bond, Vander-Waal's Bond,
Calculation of Cohesive Energy.

2. Crystallography and Crystal Structures: Space Lattice**,** Unit Cell, Lattice Parameters, Crystal Systems,Bravais Lattices, Miller Indices, Crystal Planes and Directions, Inter Planar Spacing of Orthogonal CrystalSystems, Atomic Radius, Co-ordination Number and Packing Factor of SC, BCC, FCC, Diamond and hcp Structures, Structures of NaCl, ZnS, CsCl.

UNIT-II

3. X-ray Diffraction: Basic Principles, Bragg's Law, Laue Method, Powder Method, Applications of X- ray
Diffraction.

4. Defects in Crystals: Point Defects: Vacancies, Substitutional, Interstitial, Frenkel and Schottky Defects;Qualitative treatment of line (Edge and Screw Dislocations) Defects, Burger's Vector, Surface Defects andVolume Defects.

UNIT-III

5. Elements of Statistical Mechanics: Maxwell-Boltzman, Bose-Einstein and Fermi-Dirac Statistics(Qualitative Treatment), Photon gas , Wein's Law, Rayleigh-Jeans law,, Planck's Law of Black BodyRadiation, Concept of Electron Gas, Fermi Energy, Density of States.

6. Principles of Quantum Mechanics: Waves and Particles, de Broglie Hypothesis , Matter Waves,Davisson and Germer's Experiment, G. P. Thomson Experiment, Heisenberg's Uncertainty Principle,Schrödinger's Time Independent Wave Equation - Physical Significance of the Wave Function - Particle in
One Dimensional Potential Box.

UNIT-IV

7. Band Theory of Solids: Electron in a periodic Potential, Bloch Theorem, Kronig-Penny Model (Qualitative Treatment), Origin of Energy Band Formation in Solids, Classification of Materials into Conductors, Semi Conductors & Insulators, Concept of Effective Mass of an Electron and Hole.

UNIT-V

8. Semiconductor Physics: Fermi Level in Intrinsic and Extrinsic Semiconductors, Intrinsic Semiconductors
and Carrier Concentration, Extrinsic Semiconductors and Carrier Concentration, Equation of Continuity,Direct & Indirect Band Gap Semiconductors, Hall Effect.

9. Physics of Semiconductor Devices: Formation of PN Junction, Open Circuit PN Junction, EnergyDiagram of PN Diode, I-V Characteristics of PN Junction, PN Diode as a Rectifier (Forward and ReverseBias), Diode Equation, LED, LCD and Photo Diodes.

UNIT-VI

10. Dielectric Properties: Electric Dipole, Dipole Moment, Dielectric Constant, Polarizability, ElectricSusceptibility, Displacement Vector, Electronic, Ionic and Orientation Polarizations and Calculation ofPolarizabilities - Internal Fields in Solids, Clausius - Mossotti Equation, Piezo-electricity, Pyro-electricity and
Ferro- electricity.

11. Magnetic Properties: Permeability, Field Intensity, Magnetic Field Induction, Magnetization, MagneticSusceptibility, Origin of Magnetic Moment, Bohr Magneton, Classification of Dia, Para and Ferro MagneticMaterials on the basis of Magnetic Moment, Domain Theory of Ferro Magnetism on the basis of HysteresisCurve, Soft and Hard Magnetic Materials, Properties of Anti-Ferro and Ferri Magnetic Materials, Ferrites andtheir Applications, Concept of Perfect Diamagnetism, Meissner Effect, Magnetic Levitation, Applications of Superconductors.

UNIT-VII`

12. Lasers: Characteristics of Lasers, Spontaneous and Stimulated Emission of Radiation, Meta-stableState, Population Inversion, Lasing Action, Einstein’s Coefficients and Relation between them, Ruby Laser,Helium-Neon Laser, Carbon Dioxide Laser, Semiconductor Diode Laser, Applications of Lasers.

13. Fiber Optics: Principle of Optical Fiber, Acceptance Angle and Acceptance Cone, Numerical Aperture,Types of Optical Fibers and Refractive Index Profiles, Attenuation in Optical Fibers, Application of OpticalFibers.

UNIT-VIII

14. Acoustics of Buildings & Acoustic Quieting: Basic Requirement of Acoustically Good Hall,Reverberation and Time of Reverberation, Sabine’s Formula for Reverberation Time(Qualitative Treatment),Measurement of Absorption Coefficient of a Material, Factors Affecting The Architectural Acoustics and theirRemedies. Acoustic Quieting: Aspects of Acoustic Quieting, Methods of Quieting, Quieting for SpecificObserver**s,** Mufflers, Sound-proofing.

15. Nanotechnology: Origin of Nanotechnology, Nano Scale, Surface to Volume Ratio, QuantumConfinement, Bottom-up Fabrication: Sol-gel, Precipitation, Combustion Methods; Top-down Fabrication:Chemical Vapour Deposition, Physical Vapour Deposition, Pulsed Laser Vapour Deposition Methods, Characterization(XRD&TEM) and Applications.

TEXT BOOKS:

1. Applied Physics – P.K.Palanisamy (SciTech Publications (India) Pvt. Ltd., Fifth Print 2008).
2. Applied Physics – S.O. Pillai & Sivakami (New Age International (P) Ltd., Second Edition 2008).
3. Applied Physics – T. Bhima Shankaram & G. Prasad (B.S. Publications, Third Edition 2008).

REFERENCES:

1. Solid State Physics – M. Armugam (Anuradha Publications).
2. Modern Physics – R. Murugeshan & K. Siva Prasath – S. Chand & Co. (for Statistical Mechanics).
3. A Text Book of Engg Physics – M. N. Avadhanulu & P. G. Khsirsagar– S. Chand & Co. (for acoustics).
4. Modern Physics by K. Vijaya Kumar, S. Chandralingam: S. Chand & Co.Ltd
5. Nanotechnology – M.Ratner & D. Ratner (Pearson Ed.).
6. Introduction to Solid State Physics – C. Kittel (Wiley Eastern).
7. Solid State Physics – A.J. Dekker (Macmillan).
8. Applied Physics – Mani Naidu Pearson Education

PHYSICS

LIST OF CONTENTS

APPLIED PHYSICS

UNIT-I

1. BONDING IN SOLIDS

INTRODUCTION

In the gaseous state of matter, individual atoms or molecules can move freely in space with a velocity determined by the temperature. But in solid state, the constituent atoms or molecules that build the solid are confined to a localized region. The principle region between the two states is bonding. In gases, the atoms or molecules are free whereas in solids they are bound in a particular form because of which, they possess certain physical properties such elasticity, electrical and optical properties.

BONDING

Bonding is the physical state of existence of two or more atoms together in a bound form. The supply of external energy is required to get back the bonded atoms to the Free State as energy is needed to break the bonds. This energy is called dissociation (binding) or cohesive energy.

Bonding occurs between similar or dissimilar atoms, when an electrostatic interaction between them produces a resultant state whose energy is lesser than the sum of the energies possessed by individual atoms when they are free.

TYPES OF BONDING IN SOLIDS

Bonds in solids are classified basically into two groups namely primary and secondary bonds. Primary bonds are inter atomic bonds i.e. bonding between the atoms and secondary bonds are intermolecular bonds i.e. between the molecules.

Primary bonds

The primary bonds are interatomic bonds. In this bonding interaction occurs only through the electrons in the outermost orbit, i.e. the valence electrons. These are further classified into three types

Ionic bonding
Covalent bonding
Metallic bonding

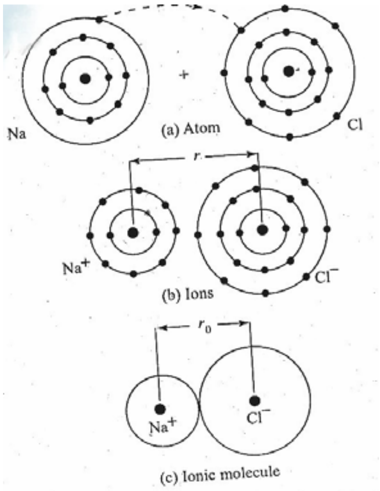
1. *Ionic Bonding* :

Ionic bonding results due to transfer of one or more electrons from an electropositive element to an electronegative element. The two types of atoms involved in the bonding are of dissimilar type.

Example:

In NaCl crystal, Na atom has only one electron in outer most shell and a Cl atom needs one more electron to attain inert gas configuration. During the formation of NaCl molecule, one electron from the Na atom is transferred to the Cl atom resulting which, both Na and Cl ions attain filled- shell configuration.

$$Na + Cl \rightarrow Na^{+} + Cl^{-} \rightarrow NaCl$$



Schematic representation of the formation of an ionic molecule of sodium chloride.

A strong electrostatic attraction is set up that bond the Na^{+} cation and the Cl^{-} anion into a very stable molecule NaCl at the equilibrium spacing.
Since Cl exist as molecules, the chemical reaction must be written as

$$2Na + Cl_2 \rightarrow 2Na^{+} + 2Cl^{-} \rightarrow 2NaCl$$

Other examples of ionic crystals are

$$2Mg + O_2 \rightarrow 2Mg^{++} + 2O^{--} \rightarrow 2MgO$$

$$Mg + Cl_2 \rightarrow Mg^{++} + 2Cl^{-} \rightarrow MgCl_2$$

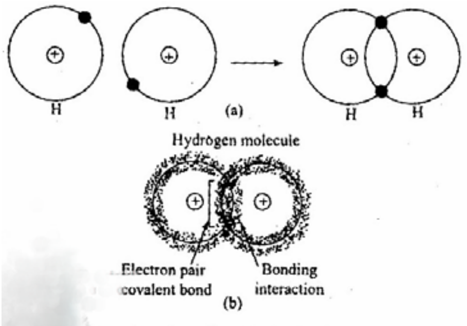
Properties:

1. As the ionic bonds are strong, the materials are hard and possess high melting and boiling points.
2. They are good ionic conductors, but poor conductors of both heat and electricity
3. They are transparent over wide range of electromagnetic spectrum
4. They are brittle. They possess neither ductility (ability to be made into sheets) nor malleability (ability to be made into wires).
5. They are soluble in polar liquids such as water but not in non-polar liquids such as ether.

2. Covalent Bonding

Covalent bond is formed by sharing of electrons between two atoms to form molecule.

Example: Covalent bonding is found in the H_2 molecule. Here the outer shell of each atom possesses 1 electron. Each H atom would like to gain an electron, and thus form a stable configuration. This can be done by sharing 2 electrons between pairs of H atoms, there by producing stable diatomic molecules.



Covalent bonding in the hydrogen molecule

Thus covalent bonding is also known as shared electron pair bonding.

Properties:

1. Covalent crystals are very hard since the bond is strong. The best example is diamond which is the hardest naturally occurring material and possess high melting and boiling points, but generally lower than that for ionic crystals.
2. Their conductivity falls in the range between insulators and semiconductors. For example, Si and Ge are semiconductors, where as diamond as an insulator.
3. They are transparent to electromagnetic waves in infrared region, but opaque at shorter wavelengths.

They are brittle and hard.

They are not soluble in polar liquids, but they dissolve in non-polar liquids such as ether, acetone, benzene etc.

The bonding is highly directional.

3. Metallic Bonding:

The valance electrons from all the atoms belonging to the crystal are free to move throughout the crystal. The crystal may be considered as an array of positive metal ions embedded in a cloud of free electrons. This type of bonding is called metallic bonding.

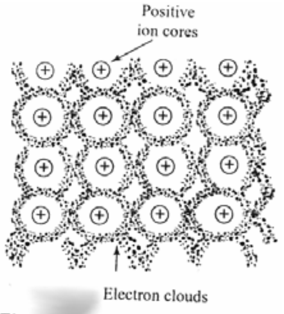


Fig. Atomic arrangement in metal crystal.

In a solid even a tiny portion of it comprises of billions of atoms. Thus in a metallic body, the no. of electrons that move freely will be so large that it is considered as though there is an electron gas contained with in the metal. The atoms lay embedded in this gas but having lost the valence electrons, they become positive ions. The electrostatic interaction between these positive ions and the electron gas as a whole, is responsible for the metallic bonding.

Properties:

1. Compared to ionic and covalent bonds, the metallic bonds are weaker. Their melting and boiling points are also lower.
2. Because of the easy movement possible to them, the electrons can transport energy efficiently. Hence all metals are excellent conductors of heat and electricity.
3. They are good reflectors and are opaque to E.M radiation.
4. They are ductile and malleable.

Secondary Bonds

There are two types of secondary bonds. They are Vander Waal's bonds and Hydrogen bonds.

1. **Vander Waal's bonding:** Vander Waal's bonding is due to Vander Waal's forces. These forces exist over a very short range. The force decreases as the 4th power of the distance of separation between the constituent atoms or molecules when the ambient temperature is low enough. These forces lead to condensation of gaseous to liquid state and even from liquid to solid state though no other bonding mechanism exists.(except He)

Properties:

1. The bonding is weak because of which they have low melting points.
2. They are insulators and transparent for visible and UV light.
3. They are brittle.
4. They are non-directional

2. **Hydrogen bonding:** Covalently bonded atoms often produce an electric dipole configuration. With hydrogen atom as the positive end of the dipole if bonds arise as a result of electrostatic attraction between atoms, it is known as hydrogen bonding.

FIG………………………..

Properties:

1. The bonding is weak because of which they have low melting points.
2. They are insulators and transparent for visible and UV light.
3. They are brittle.
4. The hydrogen bonds are directional.

Forces between atoms:

In solid materials, the forces between the atoms are of two kinds. 1) Attractive force 2) Repulsive force

To keep the atoms together in solids, these forces play an important role. When the atoms are infinitely far apart they do not interact with each other to form a solid and the potential energy will be zero. From this, it can be understood that the potential energy between two atoms is inversely proportional to some power of the distance of separation. In all atoms, moving electric charges will be present, hence either attractive interaction or repulsive interaction takes place as they approach each other.

The attractive forces between the atoms bring them close together until a strong repulsive force arises due to overlap of electron shell. The atoms attract each other when they come close to each other due to inter-atomic attractive force which is responsible for bond formation. Suppose two atoms A and B experiences attractive and repulsive forces on each other, then the interatomic or bonding force ‘f(r)’ between them may be represented as

$$F(r)=A / r^{M} - B / r^{N} \qquad (N > M)\text{--------------}(1)$$

Where ‘r ‘ is the interatomic distance

A, B, M, N are constants.

In eqn-1, the first term represents attractive force and the second the repulsive force.

At larger separation, the attractive force predominates. The two atoms approach until they reach equilibrium spacing. If they continue to approach further, the repulsive force pre dominates, tending to push them back to their equilibrium spacing.

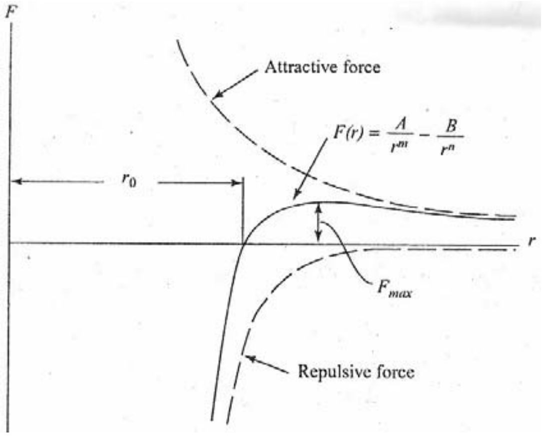


Fig. Variaration of interatomic force with interatomic spacing

To calculate equilibrium spacing r_0 :

The general expression for bonding force between two atoms is

$$F(r)=A / r^M - B / r^N$$

At equilibrium spacing $r = r_0$, $F = 0$

Hence $\mathbf{A / r_0^M = B / r_0^N}$

i.e. $(r_0)^{N-M} = B / A$

or $r_0 = (B / A)^{1/(N-M)}$

Cohesive energy:

The energy corresponding to to the equilibrium position $r = r_0$ is called the bonding energy or the energy of cohesion of the molecule. Since this is the energy required to dissociate the atoms, this is also called the energy of dissociation.

The potential energy or stored internal energy of a material is the sum of the individual energies of the atoms plus their interaction energies. Consider the atoms are in the ground state and are infinitely far apart. Hence they do not interact with each other to form a solid. The potential energy, which is inversely proportional to some power of the distance of separation, is nearly zero. The potential energy varies greatly with inter-atomic separation. It is obtained by integrating the eqn –(1)

$$U(r) = \int F(r)dr$$

$$= \int [A/r^M - B/r^N] dr$$

$$= [(A/1-M)x\, r^{1-M} - (B/1-N)x\, r^{1-N}] + c$$

$$= [-(A/M-1)\, r^{-(M-1)} + (B/N-1)\, r^{-(N-1)} + c$$

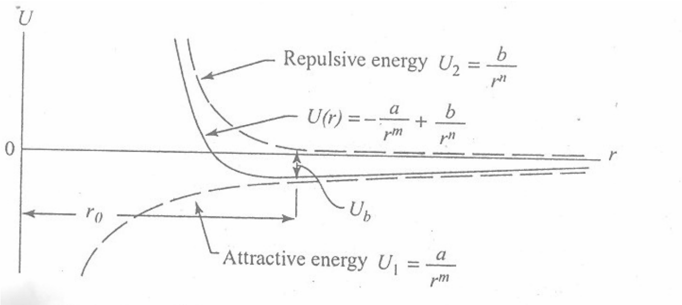
$= -a / r^m + b / r^n + c$ where $a = A/M-1$, $b = B/N-1$, $m = M-1$, $n = N-1$

At $r = \alpha$, $U(r) = 0$, then $c = 0$

Therefore $U(r) = -a / r^m + b / r^n$

The condition under which the particles form a stable lattice is that the function U(r) exhibits min. for a finite value of r i.e. $r = r_0$ this spacing r_0 is known as equilibrium spacing of the system. This min. energy Umin at $r = r_0$ is negative and hence the energy needed to dissociate the molecule then equals the positive quantity of (- Umin). Umin occurs only if m and n satisfy the condition n>m

When the system in equilibrium then $r = r_0$ and $U(r) = U_{min}$



Variation of potential energy U with interatomic spacing r.

$[dU / dr]_{r = ro} = 0$

$= d / dr\, [-a / r_o^m + b / r_o^n] = 0$

or $0 = [a\, m\, ro^{-m-1}] - [b\, n\, ro^{-n-1}]$

or $0 = [a\, m / r_o^{m+1}] - [b\, n / r_o^{n+1}]$ -------→ (2)

Solving for r_o

$r_o = [(b / a)(n / m)]^{1/n-m}$

or $r_o^n = r_o^m [(b /a)(n / m)]$

at the same time , n>m to prove this,

$[d^2U / dr^2]_{r = ro} = -[a\, m(m+1) / r_o^{m+2}] + [b\, n(n+1) / r_o^{n+2}] > 0$

$[r_o^{m+2}\, b\, n(n+1)] - [r_o^{n+2} a\, m(m+1)] > 0$

$r_o^m\, b\, n(n+1) > r_o^n\, a\, m(m+1)$

$b\, n(n+1) > a\, m(m+1)\, r_o^{n-m}$

$b\, n(n+1) > a\, m(m+1)(b / a)(n / m)$

i.e. $n > m$

Calculation of cohesive energy:

The energy corresponding to the equilibrium position $r = r_0$ **,** denoted by $U(r_0)$ is called boning energy or cohesive energy of the molecule.

Substituting 'r_o^n' in expression for U_{min},

We get

$$U_{(min)} = - a / r_o^m + b / r_o^n$$

$$= - a / r_o^m + b\ (a / b)\ (m/ n)1 / r_o^m$$

$$= - a / r_o^m + (m/ n)\ (a / r_o^m)$$

$$= - a / r_o^m[1-m / n]$$

$$U_{min} = - a / r_o^m\ [1-m / n]$$

Thus the min. value of energy of U_{min} is negative. The positive quantity $|U_{min}|$ is the dissociation energy of the molecule, i.e. the energy required to separate the two atoms.

Calculation of cohesive energy of NaCl Crystal

Let Na and Cl atoms be free at infinite distance of seoarartion. The energy required to remove the outer electron from Na atom (ionization energy of Na atom), leaving it a Na+ ion is 5.1eV.

i.e. $Na + 5.1eV \rightarrow Na^+ + e^-$

The electron affinity of Cl is 3.6eV. Thus when the removed electron from Na atom is added to Cl atom, 3.6eV of energy is released and the Cl atom becomes negatively charged.

Hence $Cl + e^- \rightarrow Cl^- + 3.6eV$

Net energy = 5.1 – 3.6 = 1.5 eV is spent in creating Na^+ and Cl^- ions at infinity.

Thus $Na + Cl + 1.5\ eV \rightarrow Na^+ + Cl^-$

At equilibrium spacing r0= 0.24nm, the potential energy will be min. and the energy released in the formation of NaCl molecule is called bond energy of the molecule and is obtained as follows:

$$V = e^2 / 4\Pi\varepsilon_0\ r_0$$

$$= - [\ (1.602\times10^{-19})^2\ /\ 4\Pi(8.85\times10^{-12})(\ 2.4\times10^{-10})\ ]\ \text{joules}$$

$= - [(1.602\times10^{-19})^2 / 4\Pi(8.85\times10^{-22}\times2.4)(1.602\times10^{-19})]$ eV

$= -6$ eV

Thus the energy released in the formation of NaCl molecule is (5.1 - 3.6 – 6) = - 4.5 eV

To dissociate NaCl molecule into Na^+ and Cl^- ions, it requires energy of 4.5 eV.

Madelung Constant

Let r be the distance of separation between the two ions, z1 and z2 be the atomic numbers of the respective nuclei.

The coulomb's force of attraction F between the positive and negative ions is,
$F = (z_1z_2)e^2 /4\Pi\varepsilon_0r^2$

The work done while they move under the attractive force towards each other through a distance dr,

$W = Fdr = [(z_1z_2)e^2 / 4\Pi\varepsilon_0r^2]\, dr$

Therefore the work done while they move from infinite distance of separation to a distance r,

$$= {}_{\infty}\int^{r} fdr = [(z_1z_2)e^2 / 4\Pi\varepsilon_0]\, {}_{\infty}\int^{r} dr/ r^2$$

$$= - (z_1z_2)e^2 / 4\Pi\varepsilon_0\, r$$

Work done by them becomes the attractive potential energy U_a

Therefore $U = - (z_1z_2)e^2 / 4\Pi\varepsilon_0\, r$

$$= - \alpha\, [e^2 / 4\Pi\varepsilon_0\, r]$$

Where α is constant called Madelung constant which has different values for different crystals.

2. CRYSTALLOGRAPHY AND CRYSTAL STRUCTURES

CRYSTALLOGRAPHY

The branch of science which deals with the study of geometric form and other physical properties of the crystalline solids by using X-rays, electron beam, and neutron beams etc is called crystallography or crystal physics.

The solids are classified into two types crystalline and amorphous. A substance is said to be crystalline, when the arrangement of atoms, molecules or ions inside it is regular and periodic. Ex. NaCl, Quartz crystal. Though two crystals of same substance may look different in external appearance, the angles between the corresponding faces are always the same. In amorphous solids, there is no particular order in the arrangement of their constituent particles. Ex. Glass.

CRYSTALLINE SOLIDS	**AMORPHOUS SOLIDS**
1. Crystalline solids have regular periodic Arrangement of particles (atoms, ions, Or molecules).	1. Amorphous solids have no regularity in the arrangement Of particles.
2. They are un-isotropic i.e., they differ in Properties with direction.	2. They are usually isotropic i.e., They possess same properties in different directions.
3. They have well defined melting and Freezing points. Melting and freezing points occurs at different temperatures at different locations in the solids.	3. They do not posses well defined melting and freezing points.
4. Crystalline solids my be made up of materials are metallic crystals or non-metallic crystals. Some of the metallic crystals are Copper, silver, aluminum, tungsten, and manganese. Non-metallic crystals are crystalline carbon, crystallized polymers or plastics.	4. Most important amorphous glasses, plastics and rubber.
5. Metallic crystals have wide use in engineering because of their favorable Properties of strength, ductility, conductivity and reflection.	5. An amorphous structure does not generally posses elasticity but only plasticity.

Lattice points: They are the imaginary points in space about which the atoms are located.

Lattice: The regular repetition of atomic, ionic or molecular units in 2-dimensional, 3-dimensional space is called lattice.

Space lattice or Crystal lattice: The totality of all the lattice point in space is called space lattice, the environment about any two points is same or An array of points in space such that the environment about each point is the same.

Consider the case of a 2-dimensional array of points.

Let O be any arbitrary point as origin, r1, r2 are position vectors of any two lattice points joining to O.

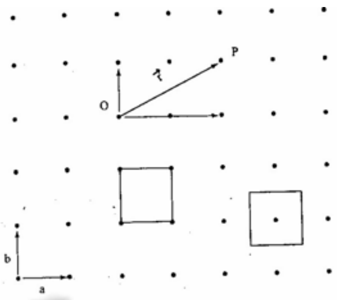


Fig. A two-dimensional square array of points.

If T (translational vector) is the difference of two vectors r1, r2 and if it satisfies the condition

$$T= n_1a + n_2b \quad \text{where } n_1, n_2 \text{ are integers}$$

Then T represent 2-dimensional lattice.

For 3- dimensional lattice,

$$T= n_1a + n_2b + n_3c$$

Note: crystal lattice is the geometry of set of points in space where as the structure of the crystal is the actual ordering of the constituent ions, atoms, molecules in space

Basis and Crystal structure:

Basis or pattern is a group of atoms, molecule or ions identical in composition, arrangement and orientation. When the basis is repeated with correct periodicity in all directions, it gives the actual crystal structure.

Crystal structure = Lattice + Basis

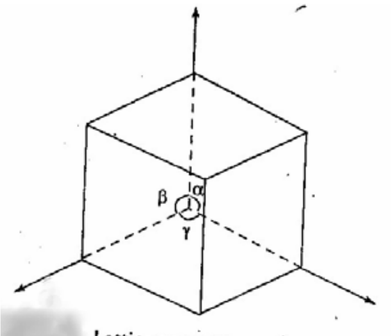
FIG………………………..

The crystal structure is real while the lattice is imaginary.

In crystalline solids like Cu and Na, the basis is a single atom
In NaCl and CsCl- basis is diatomic
In CaF_2 – basis is triatomic

Unit cell and Lattice parameters:

Unit cell is the smallest portion of the space lattice which can generate the complete crystal by repeating its own dimensions in varies directions. In describing the crystal structure, it is convenient to subdivided the structure into small repetitive entities called unit cells. Unit cell is the parallelepiped or cubes having 3 sets of parallel faces. It is the basic structural unit or the building block of the crystal.



Lattice parameters of an unit cell.

A unit cell can be described by 3 vectors or intercepts **a, b, c,** the lengths of the vectors and the interfacial angles **α, β, γ** between them. If the values of these intercepts and interfacial angles are known, then the form and actual size of the unit cell can be determined. They may or may not be equal. Based on these conditions, there are 7 different crystal systems.

Primitive Cell: A unit cell having only one lattice point at the corners is called the primitive cell. The unit cell differs from the primitive cell in that it is not restricted to being the equivalent of one lattice point. In some cases, the two coincide. Thus, unit cells may be primitive cells, but all the primitive cells need not be unit cells.

CRYSTAL SYSTEMS AND BRAVAIS LATTICES:

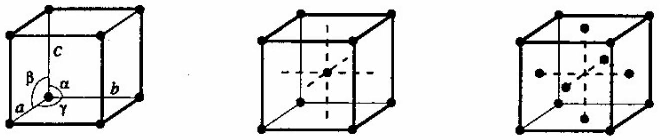
There are 7 basic crystal systems which are distinguished based on three vectors or the intercepts and the 3 interfacial angles between the 3 axes of the crystal. They are

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

More space lattices can be constructed by atoms at the body centres of unit cells or at the centres of the faces. Based on this property, bravais classified the space lattices into 14.

1. Cubic crystal system

$a = b = c, \alpha = \beta = \gamma = 90^0$



Simple

Body-centered
(bcc)

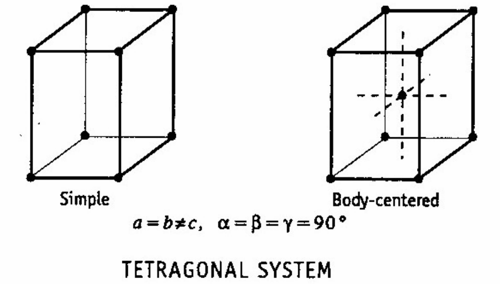
Face-centered
(fcc)

$a=b=c, \ \alpha=\beta=\gamma=90°$

The crystal axes are perpendicular to one another, and the repetitive interval in the same along all the three axes. Cubic lattices may be simple, body centered or face-centered.

2. Tetragonal crystal system

$a = b \neq c, \alpha = \beta = \gamma = 90^0$



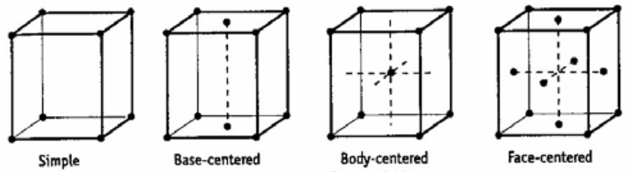
$a = b \neq c, \alpha = \beta = \gamma = 90°$

TETRAGONAL SYSTEM

The crystal axes are perpendicular to one another. The repetitive intervals along the two axes are the same, but the interval along the third axes is different. Tetragonal lattices may be simple or body-centered.

3. Orthorhombic crystal system.

$a \neq b \neq c, \alpha = \beta = \gamma = 90^0$



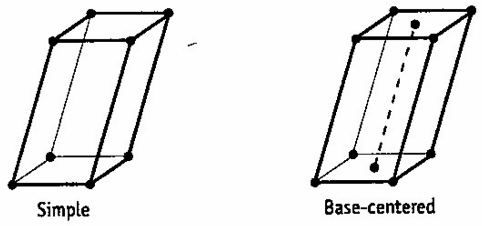
$a \neq b \neq c$; and $\alpha = \beta = \gamma = 90°$

ORTHORHOMBIC SYSTEM

The crystal axes are perpendicular to one another but the repetitive intervals are different along the three axes. Orthorhombic lattices may be simple, base centered, body centered or face centered.

4. Monoclinic crystal system

$a \neq b \neq c, \alpha = \beta = 90^0 \neq \gamma$



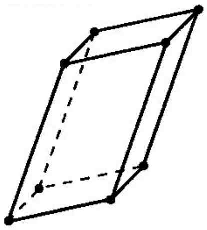
$a \neq b \neq c, \alpha = \gamma = 90° \neq \beta$

MONOCLINIC SYSTEM

Two of the crystal axes are perpendicular to each other, but the third is obliquely inclined. The repetitive intervals are different along all the three axes. Monoclinic lattices may be simple or base centered.

5. Triclinic crystal system

$a \neq b \neq c, \alpha \neq \beta \neq \gamma \neq 90^0$

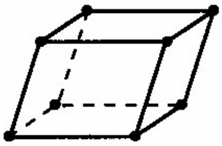


$a \neq b \neq c$
$\alpha \neq \beta \neq \gamma \neq 90°$
TRICLINIC SYSTEM

None of the crystal axes is perpendicular to any of the others, and the repetitive intervals are different along the three axes.

6. Trigonal(rhombohedral) crystal system

$a = b = c, \alpha = \beta = \gamma \neq 90^0$

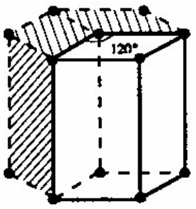


$a = b = c$
$\alpha = \beta = \gamma \neq 90°$
IOMBOHEDRAL (TRIGONAL) SYSTEM

The three axes are equal in length and are equally inclined to each other at an angle other than 90^0

7. Hexagonal crystal system.

$a = b \neq c, \alpha = \beta = \gamma = 90^0 , \gamma = 120^0$



$a = b \neq c$
$\alpha = \beta = 90°, \ \gamma = 120°$
HEXAGONAL SYSTEM

Two of the crystal axes are 60^0 apart while the third is perpendicular to both of them. The repetitive intervals are the same along the axes that are 60^0 apart, but the interval along the third axis is different.

Basic Crystal Structures:

The important fundamental quantities which are used to study the different arrangements of atoms to form different structure are

1. **Nearest neighbouring distance** (2r) : the distance between the centres of two nearest neighbouring atoms is called nearest neighbouring distance. If r is the radius of the atom, nearest neighbouring distance= 2r.
2. **Atomic radius** (r) : It is defined as of the distance between the nearest neighbouring atoms in a crystals.
3. **Coordination number** (N): It is defined as the number of equidistant nearest neighbours that an atom as in a given structure. More closely packed structure as greater coordination number.
4. **Atomic packing factor or fraction**: It is the ratio of the volume occupied by the atoms in unit cell(v) to the total volume of the unit cell (V).

P.F. = v/ V

Simple cubic (SC) structure:

In the simple cubic lattice, there is one lattice point at each of the 8 corners of the unit cell. The atoms touch along cubic edges.

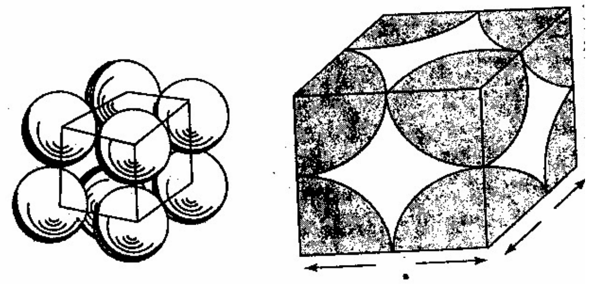


Fig. Simple Cubic Structure

Nearest neighbouring distance = 2r = a

Atomic radius = r = a / 2

Lattice constant = a = 2r

Coordination number = 6 (since each corner atom is surrounded by 6 equidistant nearest neighbours)

Effective number of atoms belonging to the unit cell or no. of atoms per unit cell = $\left(\frac{1}{8}\right)$x8 = 1 atom per unit cell.

$$\text{Atomic packing factor} = v/\,V\_ = \frac{\text{volume of the all atoms in the unit cell}}{\text{volume of the unit cell.}}$$

$$= 1 \times (4/3)\,\Pi\, r^3 / a^3 = 4\Pi\, r^3 / 3(2r)^3$$

$$= \Pi / 6 = 0.52 = 52\%$$

This structure is loosely packed. Polonium is the only element which exhibits the simple cubic structure.

Body centered cube structure (BCC):

BCC structure has one atom at the centre of the cube and one atom at each corner. The centre atom touches all the 8 corner atoms.

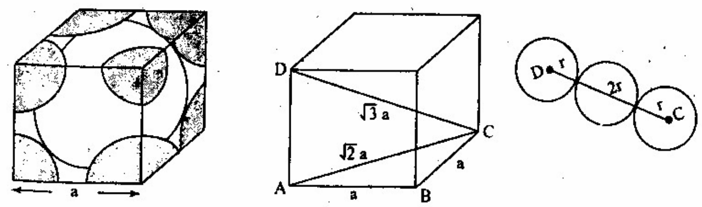


Fig. Body Centered Cubic Structure

Diagonal length = 4r

Body diagonal = $(\sqrt{3})a$

i.e. $4r = (\sqrt{3})a$

Nearest neighbouring distance = $2r = (\sqrt{3})a / 2$

Atomic radius = $r = (\sqrt{3})a / 4$

Lattice constant = $a = 4r / \sqrt{3}$

Coordination number = 8 (since the central atom touches all the corner 8 atoms)

Effective number of atoms belonging to the unit cell or no. of atoms per unit cell = $(1/8) \times 8 + 1 = 2$ atom per unit cell.

i.e. each corner atom contributes $1/8$th to the unit cell. In addition to it, there is a centre atom.

$$\text{Atomic packing factor} = v/\,V\_ = \frac{\text{volume of the all atoms in the unit cell}}{\text{volume of the unit cell.}}$$

$$= 2 \times (4/3) \prod r^3 / a^3 = 8 \prod r^3 / 3(4r/\sqrt{3}\ )^3$$

$$= \sqrt{3} \prod / 8 = 0.68 = 68\%$$

Tungsten, Na, Fe and Cr exhibits this type of structure.

Face centered cubic (FCC) structure:

In FCC structure, ther is one lattice point at each of the 8 corners of the unit cell and 1 centre atom on each of the 6 faces of the cube.

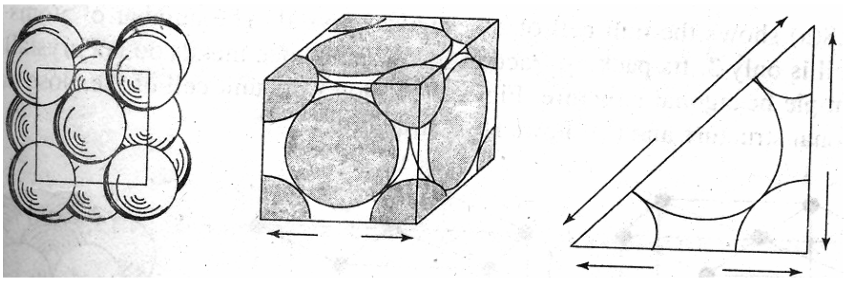


Fig. Face Centered Cubic Structure

Face diagonal length = $4r = (\sqrt{2})\, a$

Nearest neighbouring distance = $2r = (\sqrt{2})a / 2 = a / \sqrt{2}$

Atomic radius = $r = a / 2\sqrt{2}$

Lattice constant = $a = 2\sqrt{2}\, r$

Coordination number = 12 (the centre of each face has one atom. This centre atom touches 4 corner atoms in its plane, 4 face centered atoms in each of the 2 planes on either side of its plane)

Effective number of atoms belonging to the unit cell or no. of atoms per unit cell = $(1/8) \times 8 + (1/2) \times 6 = 1 + 3 = 4$ atom per unit cell.

i.e. each corner atom contributes ⅛th to the unit cell. In addition to it, there is a centre atom on each face of the cube.

Atomic packing factor = v/V = $\dfrac{\text{volume of the all atoms in the unit cell}}{\text{Volume of the unit cell.}}$

$$= 4 * (4/3) \prod r^3 / a^3 = 16 \prod r^3 / 3(2\sqrt{2}\, r\ \ )^3$$

$$= \prod / 3\sqrt{2} = 0.74 = 74\%$$

Cu, Al, Pb and Ag have this structure. FCC has highest packing factor.