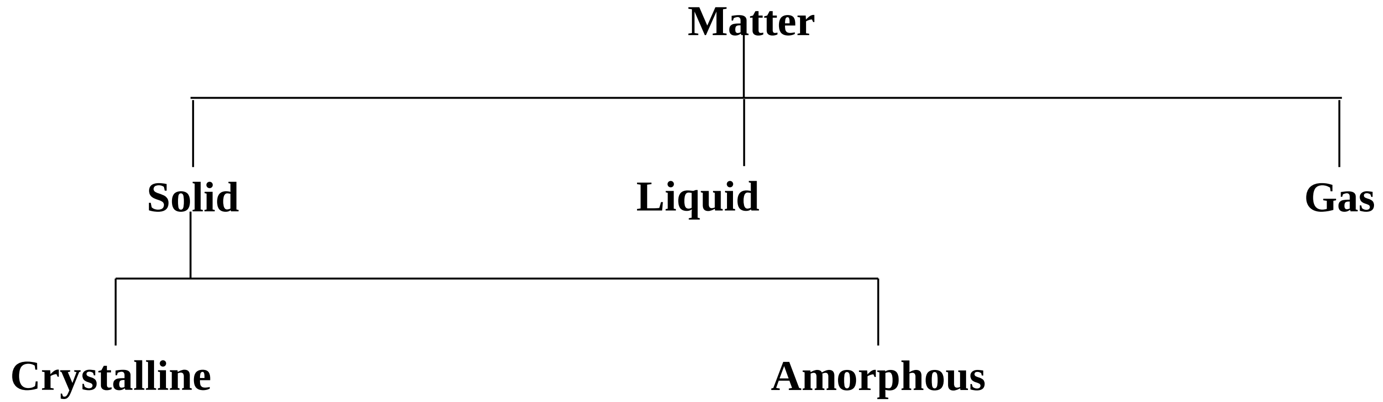
Semiconductor

Chapter one : types of matter and their bonds

Second stage: General Science

Dr Abbas



STATES OF MATTER

<u>The Four States of Matter</u>

- Solid
- Liquid
- Gas
- Plasma

.Types of solid material

- **Semiconductors**
- **Insulators**
- **Metals**

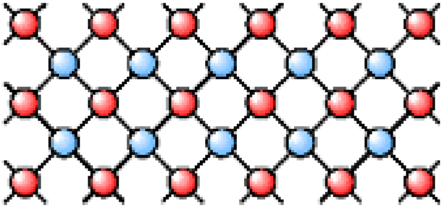
States of matter

- Based upon particle arrangement
- Based upon energy of particles
- Based upon distance between particles

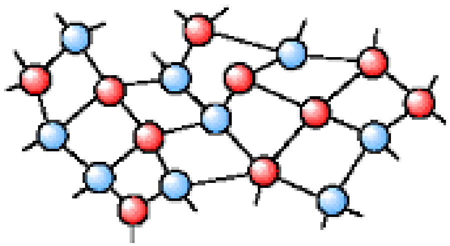
SOLIDS

can be divided into two categories

1- Crystalline **2- Amorphous**



Crystalline has long range order



Amorphous materials have short range order

Crystal?

periodic arrangement of atoms in space is called a crystal.

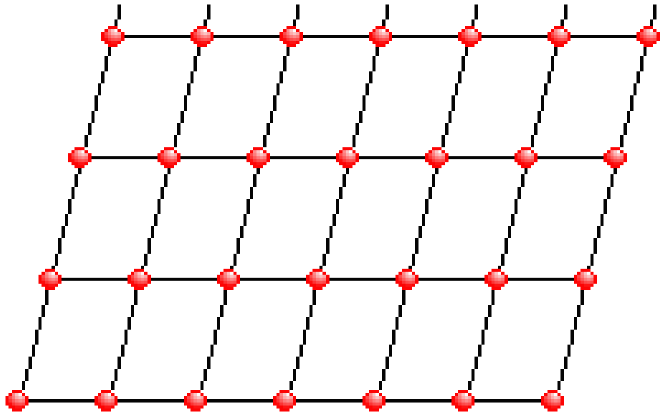
Lattice?

periodic arrangement of points in space is called a lattice.

Crystal Lattice

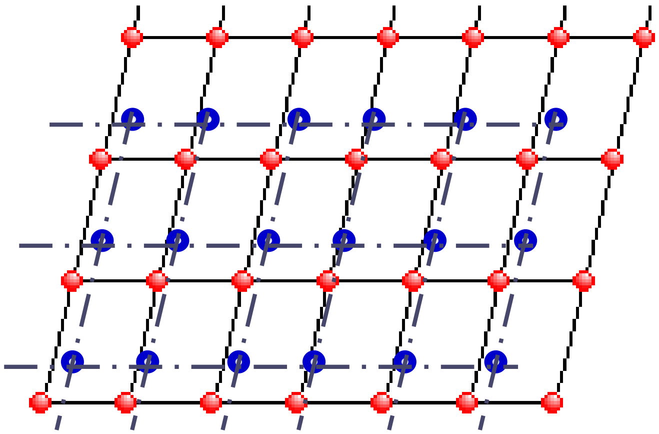
Bravais Lattice (BL)

- **All atoms are of the same kind**
- **All lattice points are equivalent**



Non-Bravais Lattice (non-BL)

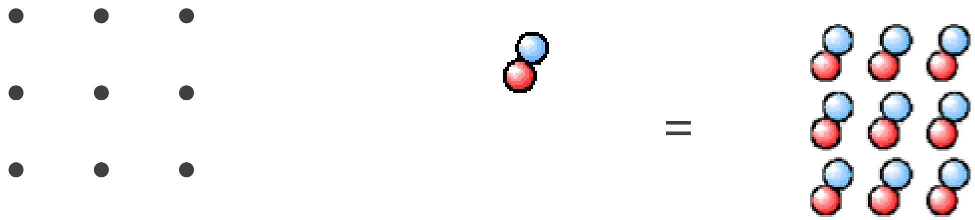
- **Atoms can be of different kind**
- **Some lattice points are not equivalent**
- **A combination of two or more BL**



CRYSTAL STRUCTURE

Crystal structure is the periodic arrangement of atoms in the crystal. Association of each lattice point with a group of atoms(Basis).

Space Lattice = Lattice of points onto which the atoms are hung.



Space Lattice + Basis = Crystal Structure

basis: an atom or a group of atoms associated with each lattice point

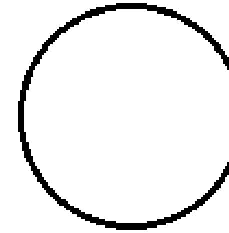
Crystal Structure

- **Crystal structure can be obtained by attaching atoms, groups of atoms or molecules**
- **which are called basis to the lattice sides of the lattice point.**

Crystal Structure = Crystal Lattice + Basis

Kinetic Theory of Matter

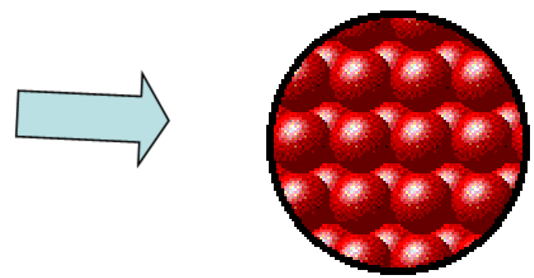
Matter is made up of particles which are in continual random motion.



STATES OF MATTER SOLIDS

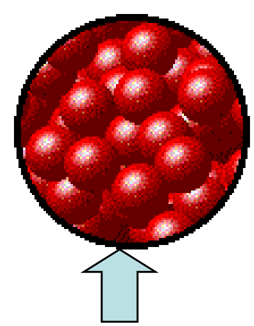
- **Particles of solids are tightly packed, vibrating about a fixed position.**
- **Solids have a definite shape and a definite volume.**

Heat



STATES OF MATTER LIQUID

- **Particles of liquids are tightly packed, but are far enough apart to slide over one another.**
- **Liquids have an <u>indefinite</u> shape and a <u>definite</u> volume.**

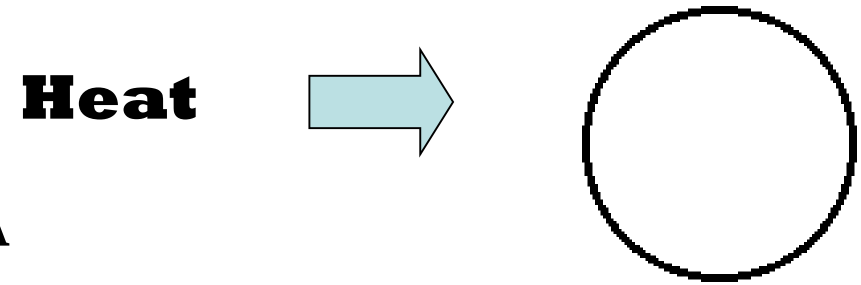


Heat

STATES OF MATTER Gas

- **Particles of gases are very far apart and move freely.**

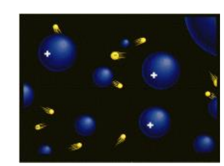
- **Gases have an indefinite shape and an indefinite volume.**



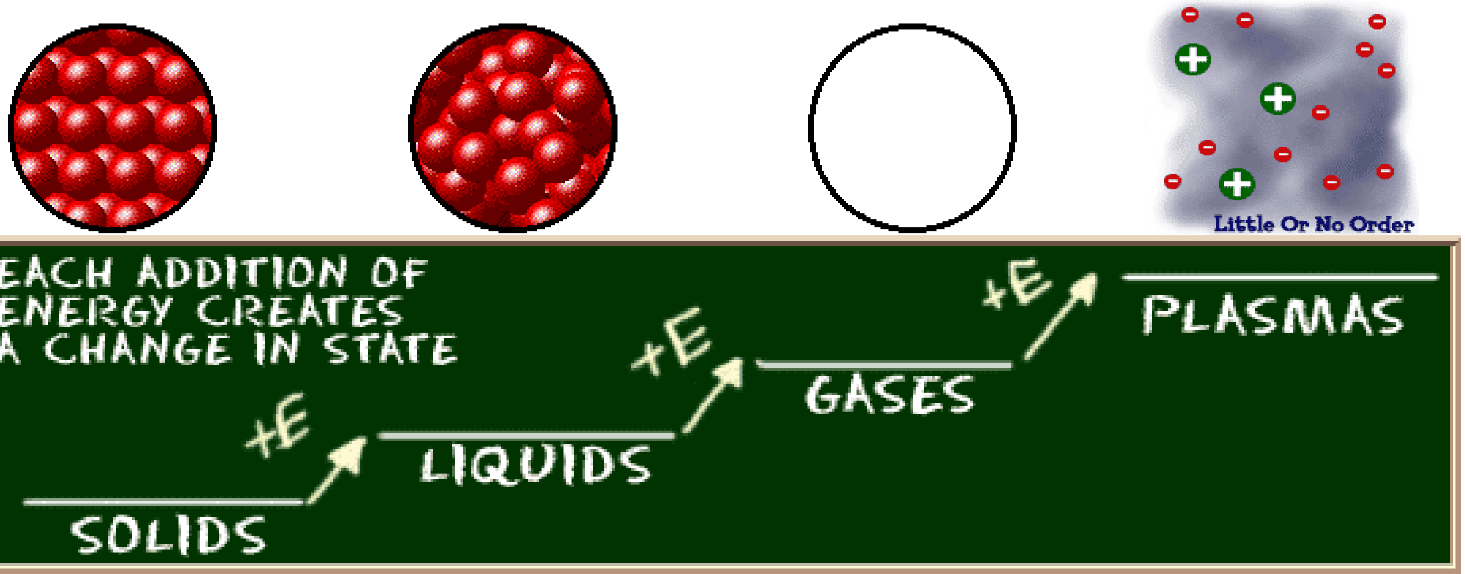
STATES OF MATTER PLASMA

- **A plasma is an ionized gas.**
- **A plasma is a very good conductor of electricity and is affected by magnetic fields.**
- **Plasmas, like gases have an indefinite shape and an indefinite volume**

- **Plasma is the common state of matter**



STATES OF MATTER



SOLID

Tightly packed, in a regular pattern Vibrate, but do not move from place to place

LIQUID

Close together with no regular arrangement. Vibrate, move about, and slide past each other

GAS

Well separated with no regular arrangement. Vibrate and move freely at high speeds

PLASMA

Has no definite volume or shape and is composed of electrical charged particles

Introduction

The forces which bind together the atoms or molecules of a substance are called bonds or bonding force. Depending upon the magnitude of this bonding force, the substance remains in different states like solid, liquid or gaseous state The magnitude of this force decreases from solid to gas.

Many physical properties of materials like melting point, boiling point, elasticity, thermal expansion, electrical and thermal conductivity are possible to predict with knowledge of the bonding forces or bonding energy.

Bonding Forces

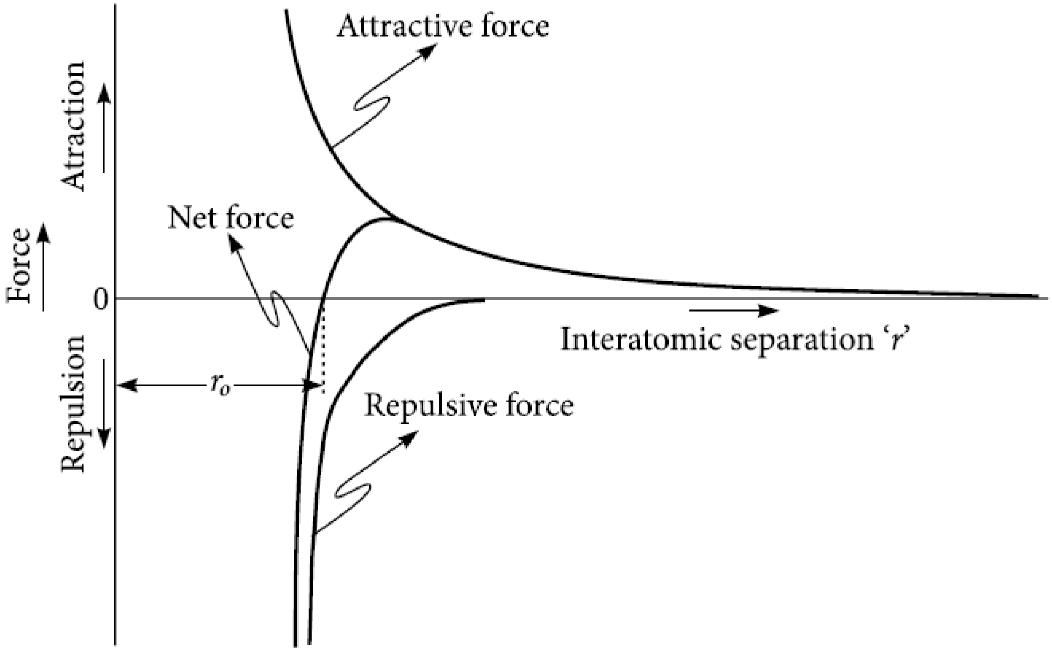
Two different forces must be present to establish bonding in a substance. An attractive force is necessary for any bonding; simultaneously, a repulsive force is required to keep the atoms from coalescing into a “point particle”. As the two atoms approach each other from a larger distance, they exert attractive and repulsive forces as shown in Fig. 4.1; the magnitude of each is a function of the inter-atomic separation. The attractive forces, which keep the atoms together forcing them to form a solid is given by

$$F_A = \frac{A}{r^i}$$

The repulsive forces which keep the atoms apart forcing them not to coalesce into a point is given by

$$F_B = -\frac{B}{r^j}$$

In these equations, *A* and *B* are proportionality constants and *i*, *j* are real numbers. The nature of these forces for two isolated atoms is illustrated in Fig.



The dependence of repulsive, attractive, and net forces on inter-atomic separation for two isolated atoms

When the outer electron shells of the two approaching atoms begin to overlap, a strong repulsive force comes into play. Further decrease of distance is not possible and atoms are at equilibrium. The reason for the strong repulsion at very short distances is Pauli's exclusion principle. At equilibrium, the attractive and repulsive forces balance each other.

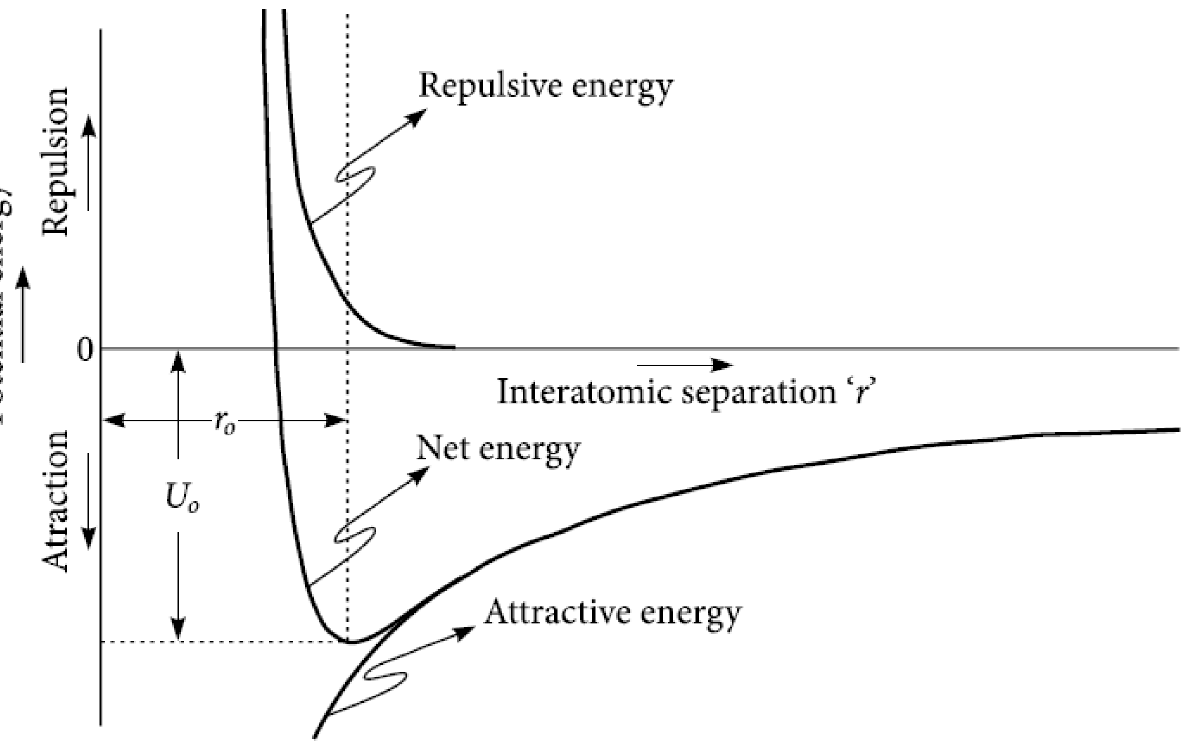
Now the atoms will oppose any attempt to disturb them. The centers of the two atoms will remain separated by the equilibrium distance r_0 as indicated in the figure.

Bonding Energies

Many times, it is more convenient to work with the potential energies between two atoms instead of forces. Mathematically potential energy *U* and force *F* are related by

$$F = \frac{\partial u}{\partial r}$$

The nature of these potential energies of two isolated atoms is illustrated in this Fig. .The total potential energy *U* is the sum of the repulsive energy *UR* and the attractive energy *UA*, i.e.,



The dependence of repulsive, attractive, and net potential energies on inter-atomic separation for two isolated atoms

$$U = U_R + U_A$$

or $$U = \frac{C}{r^m} - \frac{D}{r^n}$$

Here C and D are constants and m and n the repulsive and attractive exponents. Every system attains a stable state by acquiring minimum potential energy. When atoms come closer to form bonds, their valence electrons re-arrange themselves so as to reach a stable state by acquiring minimum potential energy. Thus, equilibrium separation r_0, corresponds to the separation distance at the minimum of the total potential energy curve.

This inter-atomic equilibrium separation r_0 is called bond length. The bonding energy U_0 is the minimum potential energy. The bonding energy is defined as the energy required to separate the atoms to an infinite separation. The magnitude of this bonding energy and the shape of the energy-versus inter-atomic separation curve vary from material to material, and they both depend on the type of atomic bonding.

Atom or atomic Hydrogen

Bohr model : explanation many properties of the hydrogen atom or Bohr's postulates as follows

This mean that atoms exist only in certain stable states with energy level $\{ E_1 \quad E_2$ -------- $E_n\}$ and with a certain radius, wavelength , velocity and energy levels.

Bohr's first postulate allowed the *orbital stability* of the electron to be given by classical mechanics, where the attractive Coulombic force is equated to the centripetal force, as given by Equation

Coulomb force $$F_{coul} = k\frac{Ze^2}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2} \qquad (1)$$

From newton's second law (centripetal force) $$F_{cen} = m\frac{v^2}{r} \qquad (2)$$

$$F_{cen} = F_{coulb} \qquad v = \sqrt{\frac{Ze^2}{4\pi\epsilon_0 mr}} = \sqrt{\frac{kZe^2}{mr}} \qquad (3) \qquad Bohrs\ first\ postulate$$

$$\boldsymbol{Electron\ radius\ of\ all\ elements\ is} \qquad \boldsymbol{n = 0.53\ \frac{n^2}{z}}$$

$$\boldsymbol{Energy\ of\ electron\ for\ all\ elements\ atom} \qquad E_n = -13.6\ eV\ \frac{Z^2}{n^2}$$

WAVELENGTH OF MATTER WAVES

$$\text{de Broglie wavelength} = \frac{\text{Planck's constant}}{\text{momentum}}$$

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

As seen by this equation, the larger the momentum of an object, the smaller its wavelength. In an analogy with photons, de Broglie postulated that the frequency of a matter wave can be found with Planck's equation as illustrated below:

FREQUENCY OF MATTER WAVES

$$\text{de Broglie frequency} = \frac{\text{energy}}{\text{Planck's constant}}$$

$$f = \frac{E}{h}$$

The dual nature of matter suggested by de Broglie is quite apparent in these two equations, both of which contain particle concepts (E and mv) and wave concepts (λ and f).

Electron Quantum State

$$\text{Electron State} \equiv (n, l, m_l, m_s)$$

$n = 1, 2, 3, 4, 5, \cdots$	Principal Quantum Number
$l = 0, 1, 2, \cdots, n = 1$	Orbital Quantum Number $l = 0, 1, 2, 3, \cdots, n-1,$
$m_l = -l, \cdots, 0, \cdots, l$	Orbital Magnetic Quantum Number $\mathbf{0. \pm 1. \pm 2 \ \pm 3 \ \ldots\ldots \pm l}$
$m_s = -\frac{1}{2}, +\frac{1}{2}$	Spin Magnetic Quantum Number
$N_n = 2n^2$	Maximum Number of Shell Electrons

Orbital angular momentum states each of these state can be filled two electron (sipn up and sipn down $2l + 1$ $\Delta \mp l$

The maximum number of electrons allowed in a *shell* $N_n = 2n^2$,

while the maximum number allowed in a *subshell* can be obtained from the equation

$$N_l = 2(2l + 1).$$

Energy States	$n = 1$	2	3	4	5	··	Maximum Number of Subshell Electrons
	↓	↓	↓	↓	↓		Atomic Energy States
Electron Shells	K	L	M	N	O	··	Names of Electron Shells
Angular Momentum States	$l = 0$	1	2	3	4	···	Angular Momentum States
	↓	↓	↓	↓	↓		
Electron Subshells	s	p	d	f	g	.	Names of Electron Subshells

angular momentum quantum number, l.

$2l + 1$ orbital angular momentum states.

$3s$ has $l = 0$; thus, $2(2l + 1) = 2(0 + 1) = 2$

$3p$ has $l = 1$; thus, $2(2l + 1) = 2(2 + 1) = 6$

$3d$ has $l = 2$; thus, $2(2l + 1) = 2(4 + 1) = 10$

Total = 18

(in the $n = 3$ shell).

A complete specification of the state of an electron in a hydrogen atom requires five quantum numbers: *n*, *l*, *m*, *s*, and *ms* .

The names, symbols, and allowed values of these quantum numbers are summarized in **Table**

There are two main type bonding

There are two main types depending on the physical origin and nature of the bonding force involved of bonding: 1) Primary bonding 2) Secondary bonding 1) Primary bonding results from the electron sharing or transfer. There are three types of primary bonding .,ionic, covalent, and metallic . In ionic bonding, atoms behave like either positive or negative ions, and are bound by Coulomb forces. A large difference in electronegativity is required for an ionic bond to be formed. The ionic bonding is nondirectional.

Covalent Bonding: In covalent bonding, electrons are shared between the molecules, to saturate the valency.

Metallic bonding: In metals, valence electrons are detached from atoms

2) Secondary bonding: There is no electron transfer or sharing in secondary bonding. Secondary bonding also called as van der Waals bonding, is much weaker as compared to the primary bonding and results from interaction of atomic or molecular dipoles. And hydrogen bond.

Solids are stable structures, e.g., a crystal of NaCl is more stable than a collection of free Na and Cl atoms.

an attractive interatomic force exists which holds the atoms together. This is the force responsible for crystal formation

This also means that the energy of the crystal is lower than that of the free atoms by an amount equal to the energy required to pull the crystal apart into a set of free atoms. This is called the *binding energy* {also the cohesive energy) of the crystal.

Binding (bond) energy is minimum energy required to separate two atoms from their equilibrium spacing to an infinite distance apart

Comparison of Different Types of Bonds

	Ionic	Covalent	Metallic	Van der Waal	Hydrogen
Principle cause of binding	Transfer of electrons between atoms and electrostatic attraction between them.	Mutual sharing of valence electrons between atoms	Attraction between the lattice of ion cores and the free electron gas.	Mutual polarization of atoms due to each other	Lowering of K.E of proton by the arrangement O- H-O.
Properties	Very strong binding	Strong binding	Moderate strong binding	Weak binding	Weak binding
	Poor electrical and thermal conductors	Conductivities over a wide range	High electrical and thermal conductivities	Poor electrical conductors	Low electrical and thermal conductivities.
	Transparent over a wide range of frequencies Closed packed structure.	Transparent to long wavelength radiation but opaque to shorter wavelength. Loose packed structure.	Opaque to all electromagnetic radiations from very low frequency to middle ultraviolet where they become transparent. Closed packed structure.	Transparent to electromagnetic radiation. Closed packed structure	Transparent Loose structure
	Non directional bond	Strongly directional bond	Non-directional bond	Non-directional bond	Peculiar directional properties
Examples	NaCl, KCl, NaBr, KBr, MgO, MgCl	CH, Cl, H, Si, Ge.	Na, K, Mg, Al, Pb.	Na, N, He, Ar, Kr, Xe	Ice, KH, PO

Classification of solids according to the bonding of atoms

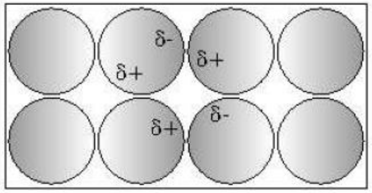
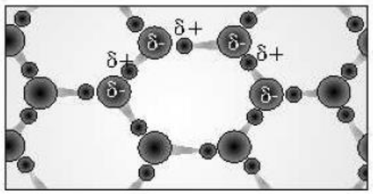
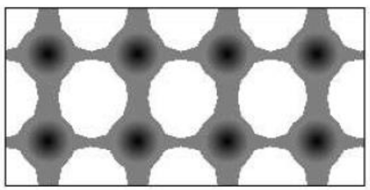
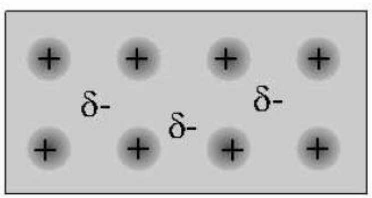
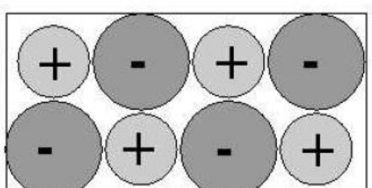
Type	Schematic	Cohesive Energy	Examples	Binding energy $\frac{eV}{atoms}$
Van der Waals		Weak: 0.05--0.3 eV	Noble Gases (Ar, Ne, etc), Liquid O_2	**0.05 0.3**
H bonding		Weak: 0.1-0.5 eV	Water, Ice, Proteins	**0-5**
Covalent		Strong: ≤11 eV (molecules) ≤8 eV (solids)	C (graphite, diamond), Si	**2 -6**
Metallic		Strong: ≤9 eV	Na, Al, Transition Metals	**1-1.5**
Ionic		Strong: ≤8 eV	NaCl; NaBr, KI	**0-2**

Figure : *Very* simple summary of the main types of bonding in solids