Modern Materials- Contents

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References:

- ***Engg.Chemistry*** *by*
  Jain and Jain

- ***Engg.Chemistry*** *by*
  Dr. R.V.Gadag and Dr. A.Nithyananda Shetty

- ***Principles of Physical Chemistry*** *by*
  Puri and Sharma

- ***Essentials of Engineering Chemistry*** by
  S.K. Bhasin and Vijay Sharma

Learning Objectives

- Understand the fundamental principles of material science
- Explain how functional needs are related to structure & bonding
- Apply experimental design techniques to material production
- Define liquid crystal phases & give specific examples
- Understand the essential concepts used in nanomaterial synthesis
- Discuss the types and applications of nanomaterials in different fields.

Fundamental principles of materials

Materials - substances used in the primary production or manufacturing of a goods.

Different substances ➔ different properties

- Contain different elements & different combinations of elements.
- Contain different types of chemical bonds
- Have different sizes of units
- The solid state structure may contain different types of assemblies e.g., molecular packing arrangement may be different or the geometry of linkage in an extended 3D structure may vary.

At the atomic level:
arrangement of atoms in different ways, for instance two allotropes of carbon, graphite and diamond show, different properties.

At the microscopic level:
arrangement of small grains of material provides different optical properties to transparent vs. frosted glass.

Non-metals such as C, Si, B, N, O, and P, and metals such as Al, Mg, Ti, Sn, Fe, Cu, Cr and Ni.

Other elements such as Cd, Ga, Ge, Pt, Ag and Au are also used in smaller quantities and for specialized applications.

Material science involves the study of the relationship between structure and properties of materials. The basis of materials science involves relating the desired properties and relative performance of a material in a certain application, to the structure of the atoms and phases.

Properties of materials are grouped into six categories *mechanical*, *electrical and magnetic* properties, *thermal* (transmission of heat, heat capacity), *optical* (absorption, transmission and scattering of light), and the *chemical stability* in contact with the environment (like corrosion resistance).

Classification of materials

- Solid materials
- Advanced materials
- Nanomaterials

Metals and alloys:

***E**lements which can lose their outer electrons.*

The valence electrons are detached from atoms, and spread in an 'electron sea' that "glues" the metal ions together.

Usually strong, malleable, ductile, good electrical and thermal conductors and are opaque to light but-exhibit typical metallic luster. Example: aluminum, steel, brass, gold.

Ceramics:

An inorganic, non-metallic solid prepared by the action of heat and subsequent cooling.

Usually combinations of metals or semiconductors with oxygen, nitrogen or carbon forming corresponding oxides, nitrides, and carbides. Examples: glass, porcelain, fire brick.

Polymers:

Polymers are substances of high molecular mass formed by the joining together of monomers with low molecular mass.

Bound by covalent forces and also by weak van der Waals forces, and usually synthetic polymers have a backbone of C-C bonds

Composites

Composed of two (or more) constituent materials with significantly different properties.

The design goal of a composite is to achieve a combination of properties that are not displayed by any individual materials, and also to incorporate the best characteristics of each of the component materials.

Advanced materials

Advanced materials have superior properties such as toughness, hardness, durability and elasticity when compared to conventional materials.

Materials that are used in high-technology applications are sometimes termed advanced materials. Advanced materials include

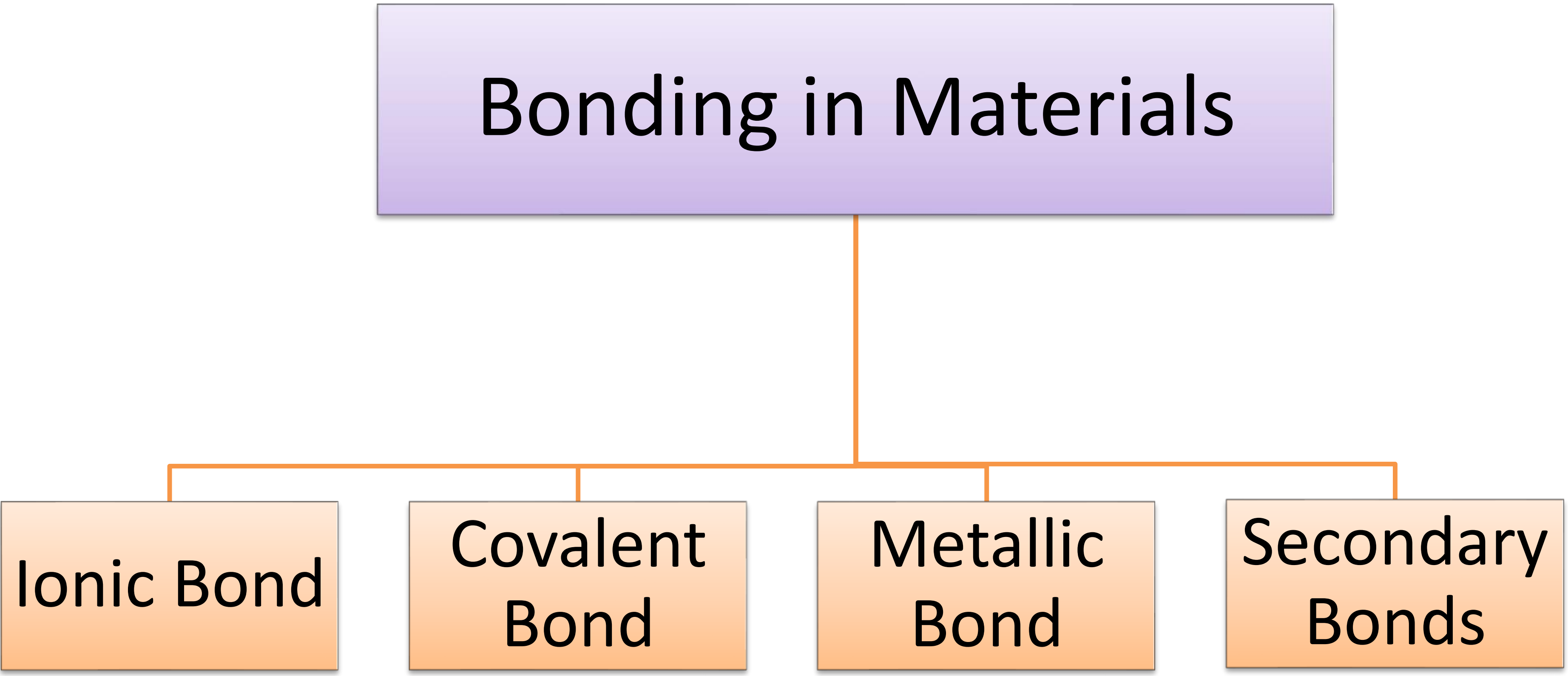
Semiconductors: A semiconductor is a material which has electrical conductivity between that of a conductor such as copper and that of an insulator such as glass. They are the building blocks of modern electronics including transistors, solar cells, light emitting diodes and integrated circuits.
Examples: Si, Ge, Ga, As.

Biomaterials

Material that has a biomedical or biological application. They might have a therapeutic use or a diagnostic use and the material must have properties that meet the demands of that applications.

Nanomaterials:

Nanomaterials are defined as materials with at least one external dimension in the size range from 1-100 nanometers.


Bonding in Materials
Ionic Bond
Covalent Bond
Metallic Bond
Secondary Bonds

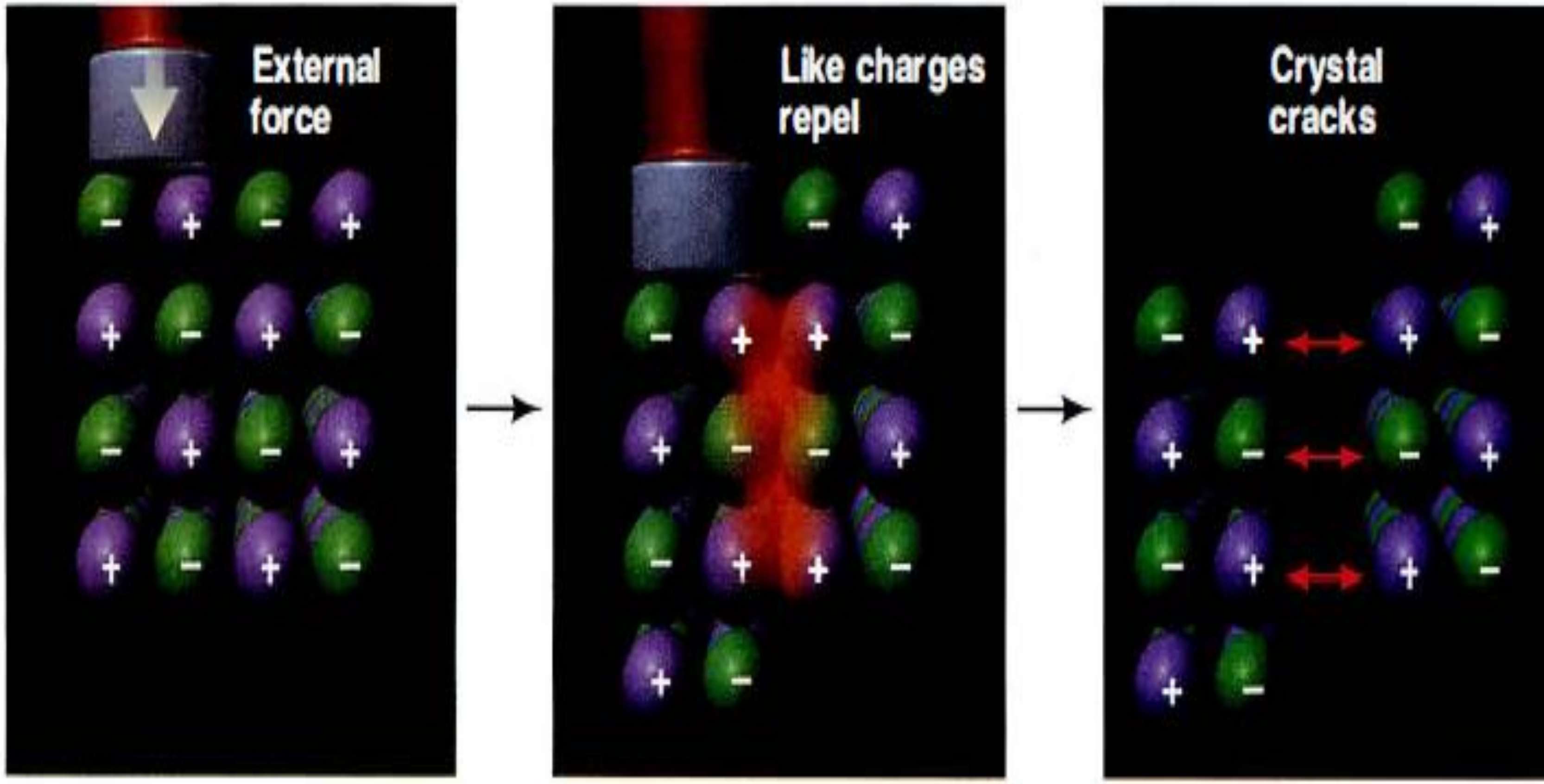
Ionic Bond

The electrostatic attraction between the cation & anion produced by electron transfer

$A^+ + B^- \rightarrow A^+ \bigcirc B^- +$ Lattice energy

electrovalent bond

$2\,Na(S) + Cl_2(g) \rightarrow 2NaCl\,(S)$

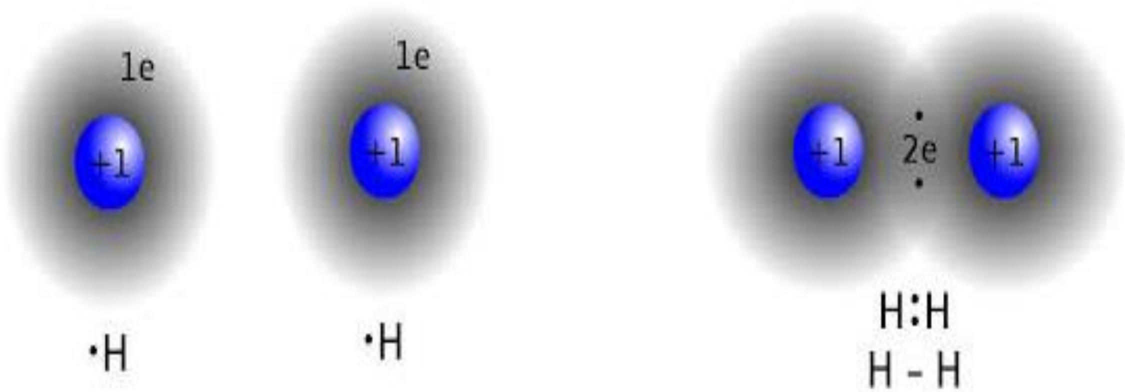

External force
Like charges repel
Crystal cracks

The characteristic properties of ionic compounds

- They are solids at room temperature
- Crystals of ionic solids are hard and brittle.
- They possess high melting points and high boiling points.
- They do not conduct electricity in the solid state. They are good conductors of electricity when they are in the molten state or in aqueous solution.
- They are soluble in polar solvents but insoluble in nonpolar solvents.
- They do not exhibit isomerism.

Covalent Bond

Formed by overlap of atomic orbitals & mutual sharing of electrons.

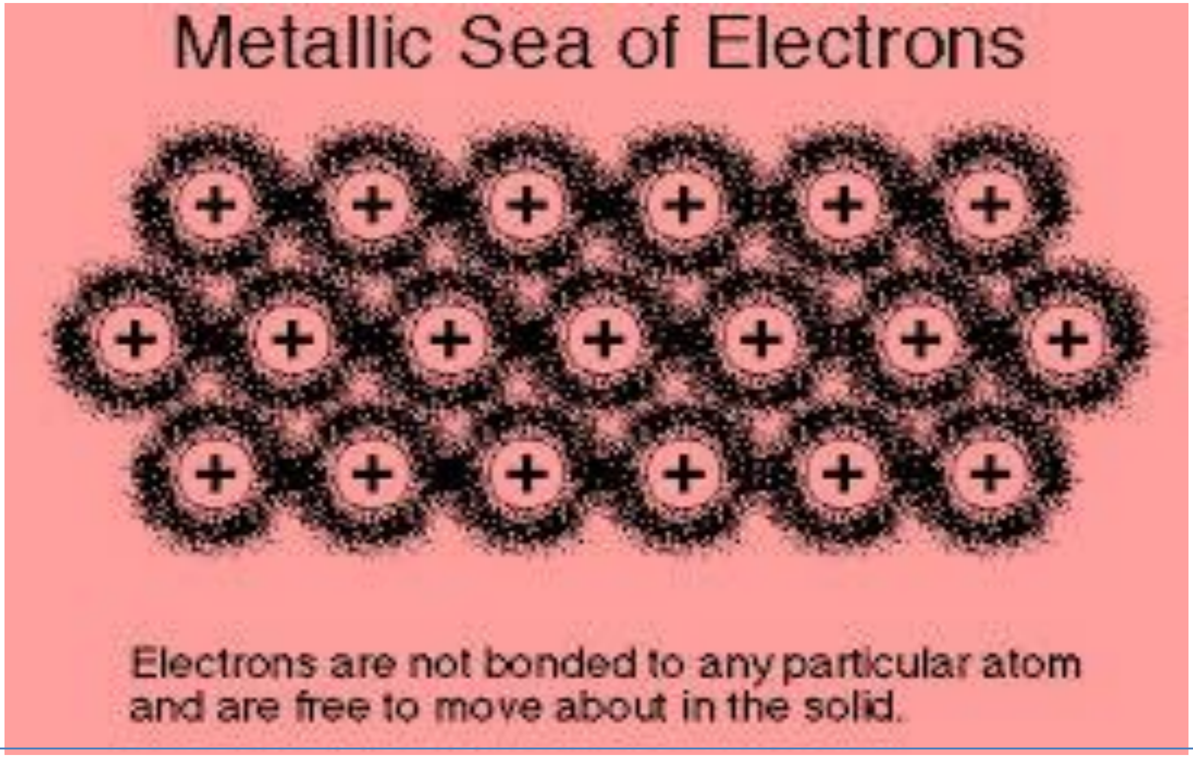


The characteristic properties of covalent compounds

- gases, liquids or solids at room temperature
- soft and much readily broken
- have low melting points and boiling points
- soluble in organic solvents
- rigid and directional; causes stereoisomerism
- do not conduct electricity in any state

Metallic bond

The bonding which holds the metal atoms firmly together by force of attraction between metal ions & the mobile electrons

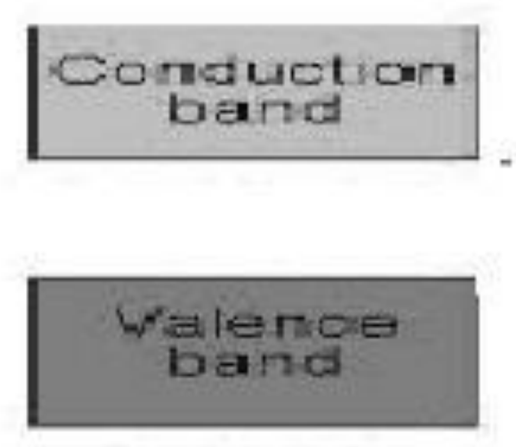


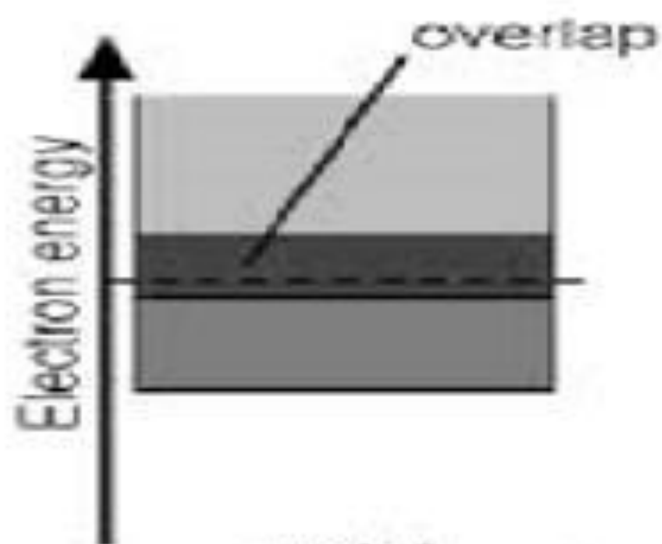
- A block of metal can be thought of as an array of positive ions immersed in a sea of delocalized electrons.

- The great cohesive forces resulting from the delocalization is responsible for the great strength noted in metals.

- The outer orbitals of a very large number of atoms overlap to form a very large number of molecular orbitals that are delocalized over the metal.

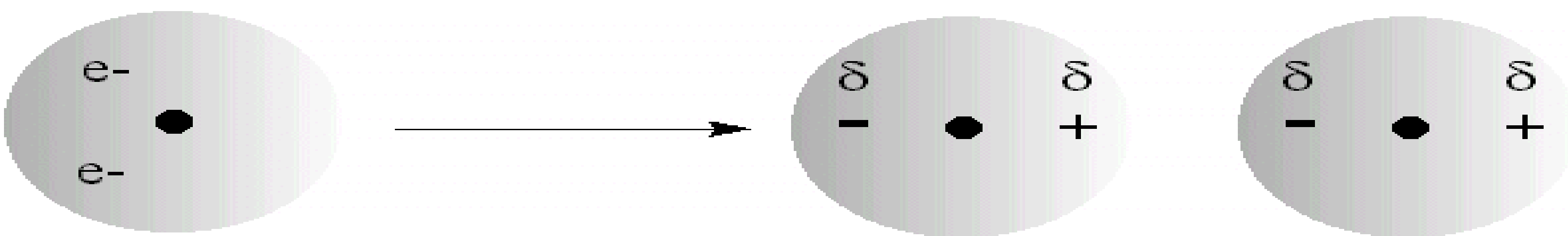
- A large number of closely spaced energy levels form ‘bands’


Conduction band
Valence band


overlap
Electron energy
metal

Secondary Bonds

- Hydrogen Bonds
- Dipole-dipole Bonds
- Dipole-Induced dipole Bonds
- London Forces



Instantaneous uneven distribution of electrons in He atom

Instantaneous dipole

Induced dipole on neighboring He atom. Resultant attractive force

- Secondary bonding exists between virtually all atoms or molecules but its presence may be obscured if any of the three primary bonding types is present.

- Secondary bonding is evidenced for the inert gases, which have stable electron structures, and in addition, between molecules in molecular structures that are covalently bonded.

- Secondary bonding forces arise from atomic or molecular dipoles

Hydrogen bonds: The electrostatic attraction between an H-atom covalently bonded to a highly electronegative atom X such as nitrogen, oxygen or fluorine and a lone pair of electrons on X in another molecule is called hydrogen bonding.

The hydrogen-bond attraction can occur between molecules (*intermolecular*) or within different parts of a single molecule (*intramolecular*).

Ion-dipole forces: This type of force exists between an ion and the partial charge on the end of a polar molecule, e.g. KBr/NaCl in water

Dipole-dipole bonds: The strongest secondary bonding type exists between adjacent polar molecules.

HCl is an example of polar molecule. The positive end of one dipole attracts the negative end of the other. There is a net attraction between the polar molecules. Generally such attractions are about 1 % as strong as a covalent bond.

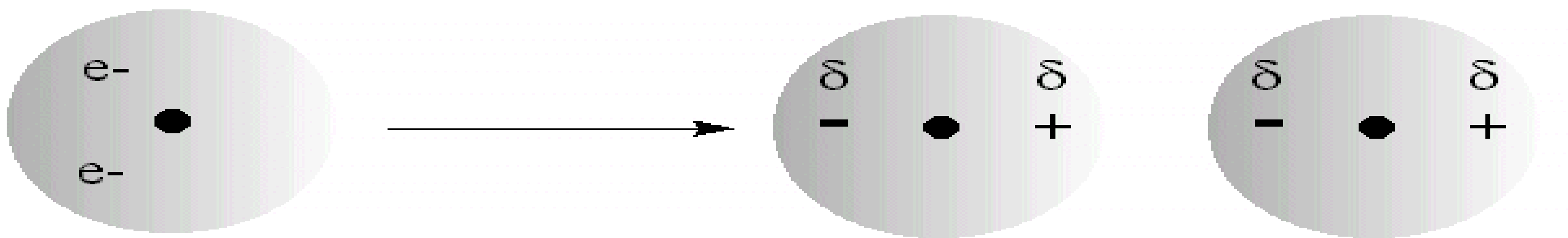
Dipole-induced dipole bonds:
Polar molecules will induce a dipole in adjacent nonpolar molecules, and a bond will form as a result of attractive forces between the dipole and induced dipole.

The magnitude of this interaction depends on the magnitude of dipole moment of the polar molecule and the polarizability of the non-polar molecule. Eg. solution of polar solutes in nonpolar solvents. (oxygen and nitrogen in water)

- All atoms are experiencing constant vibrational motion that can cause instantaneous and short-lived distortions of this electrical symmetry for some of the atoms or molecules, and the creation of small electric dipoles.

- One of these dipoles can in turn produce a displacement of the electron distribution of an adjacent molecule or atom, which induces the second one also to become a dipole that is then weakly attracted or bonded to the first.

- The momentary attraction between the molecules of a liquid caused by instant dipole and induced dipole are called London Forces.



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