Structure of Matter

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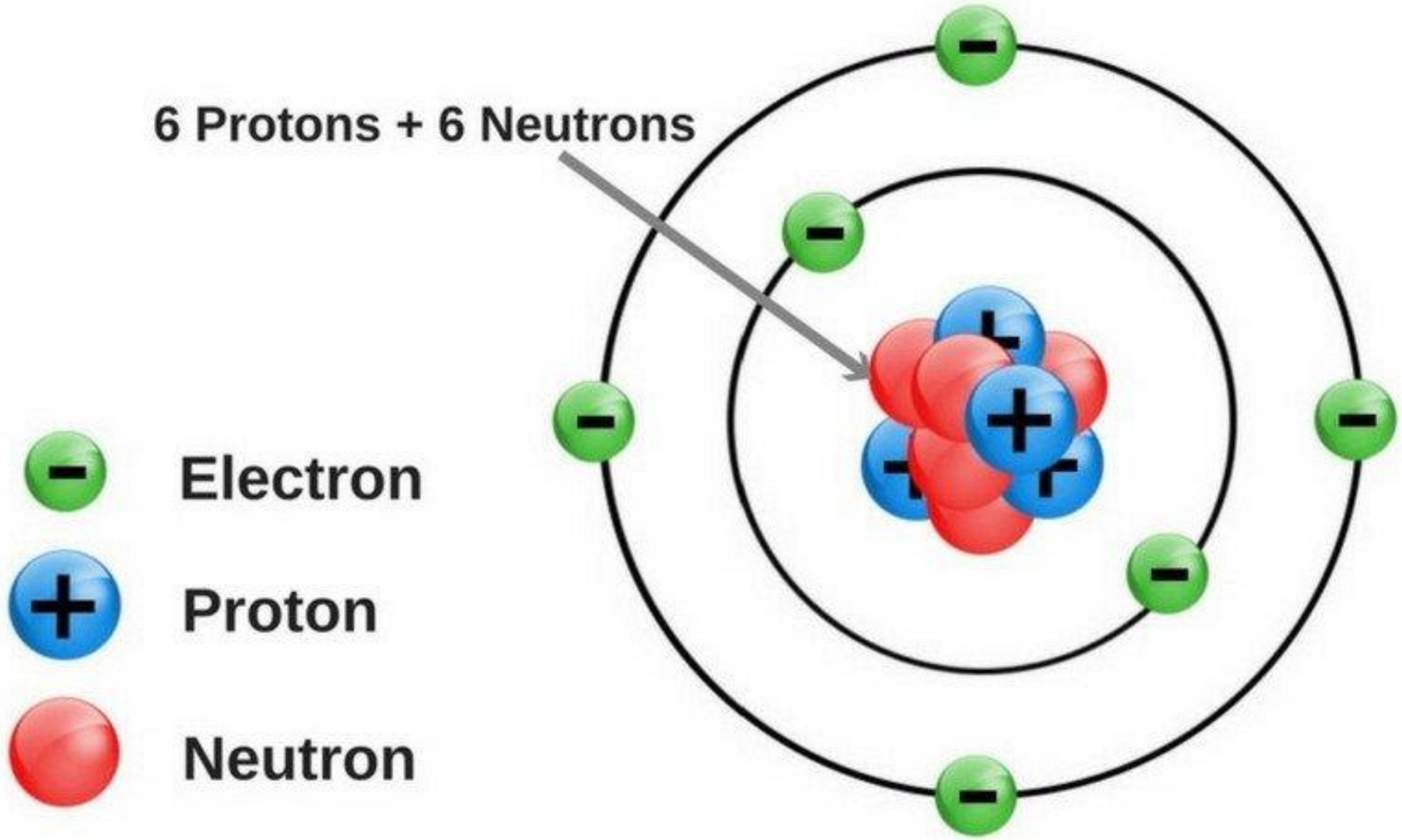
Chapter Content:

1. Atomic Structure.
2. Atomic bonds (Primary and Secondary bonds).
3. Inter-atomic distance.
4. Classification of solids (acc to bond and arrangement)
5. Atomic packing factor
6. Imperfection in crystalline solids
7. Polymorphism
8. Correlation between atomic structure and material properties

Atomic Structure:

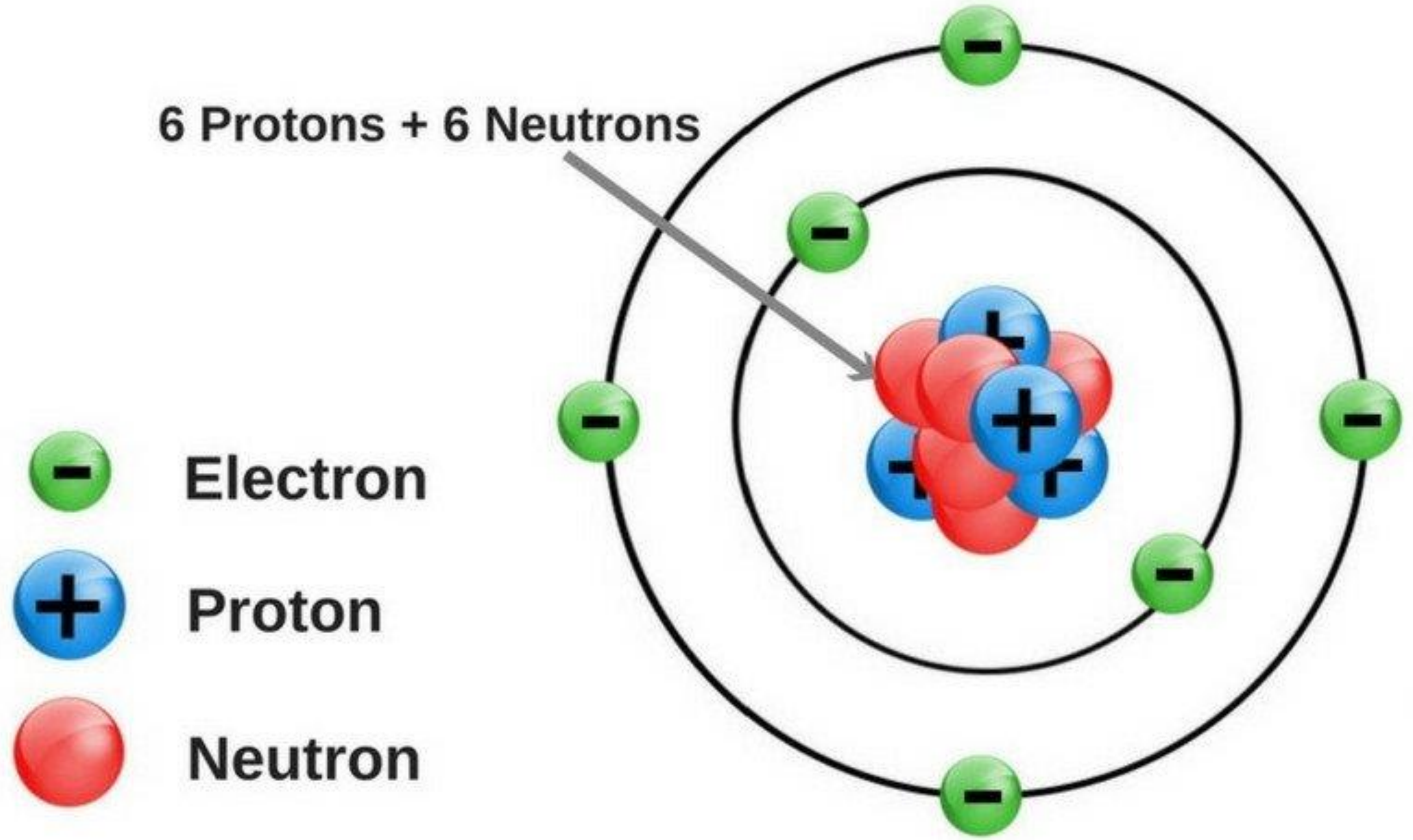
- The basic unit of any material is the atom
- The atom consists of a nucleus and surrounding electrons



Atomic Structure:

- Nucleus is the core of the atom and composed of:

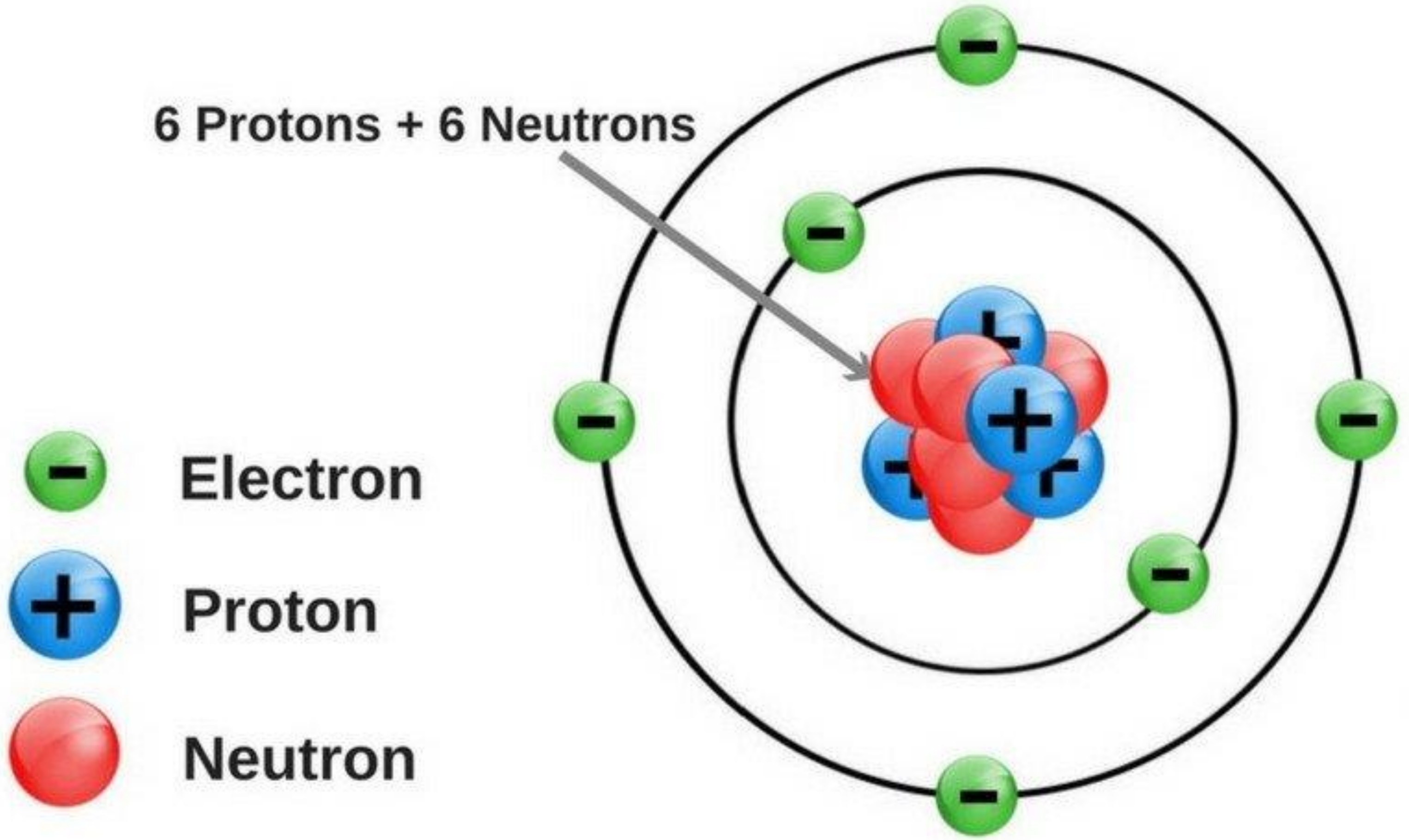
1. Positively charged protons.
2. Uncharged neutrons.



Atomic Structure:

- Electrons surround the nucleus in shells

1. Negatively charged.
2. The most outer electrons are called VALANCE ELECTRONS
3. Valence electrons affect the physical & chemical properties



Atomic Structure:

Definitions:

1. Atomic number = Number of electrons = number of protons.

2. Atomic weight = weight of protons + neutrons.

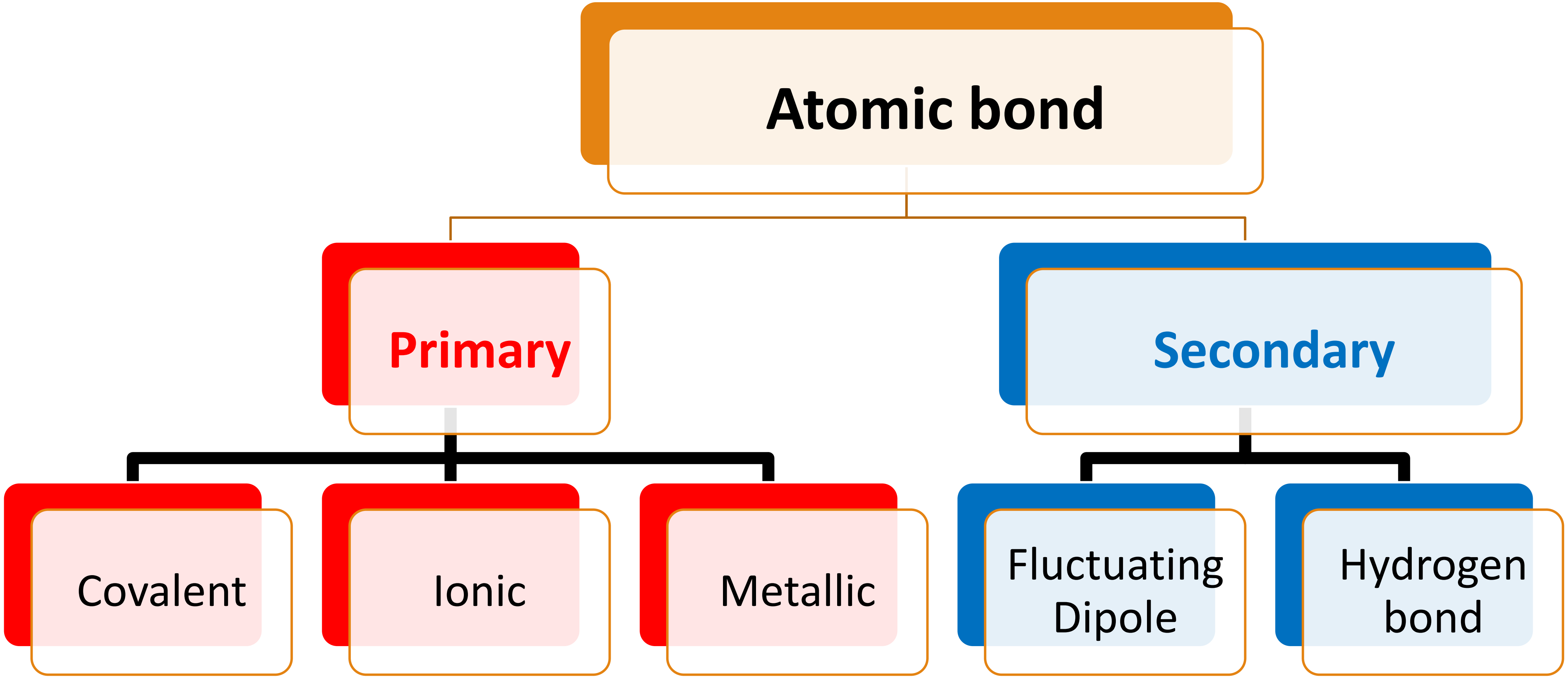
Atomic Structure:

Every element tries to reach the stable configuration by having 8 electrons in its outer shell by:

1. Releasing Electrons ➲become +ve charged
2. Receiving extra electrons ➲ become –ve charged
3. Sharing electrons with other atom

Then forming the **atomic bonds**

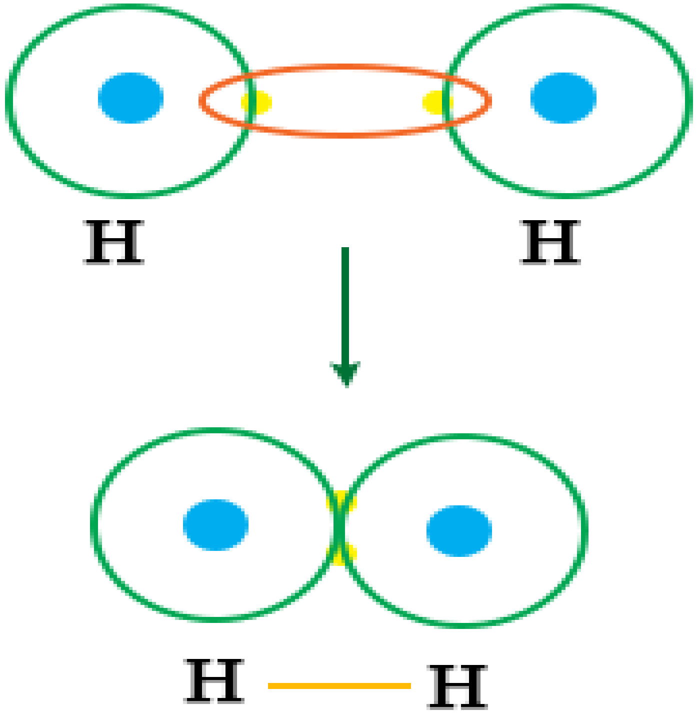
Atomic Bonds



Atomic Bonds (Primary bond)

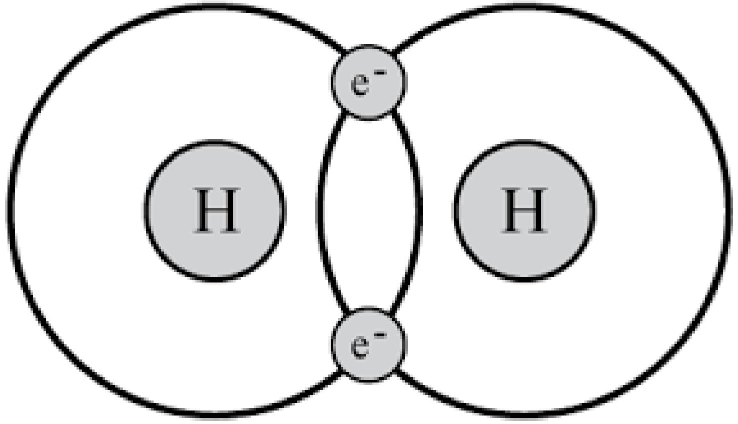
Covalent bond

Arises by **sharing** electrons between atoms, the atoms approach one another and orbital overlap happened.



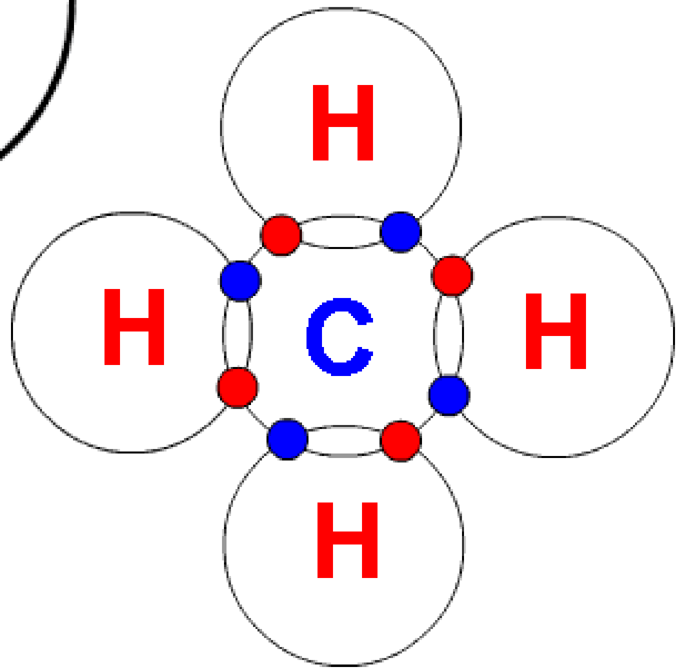
Atomic Bonds (Primary bond)

Covalent bond



Sharing between:

- Same element (e.g. H_2)
- Different elements (e.g. CH_4)

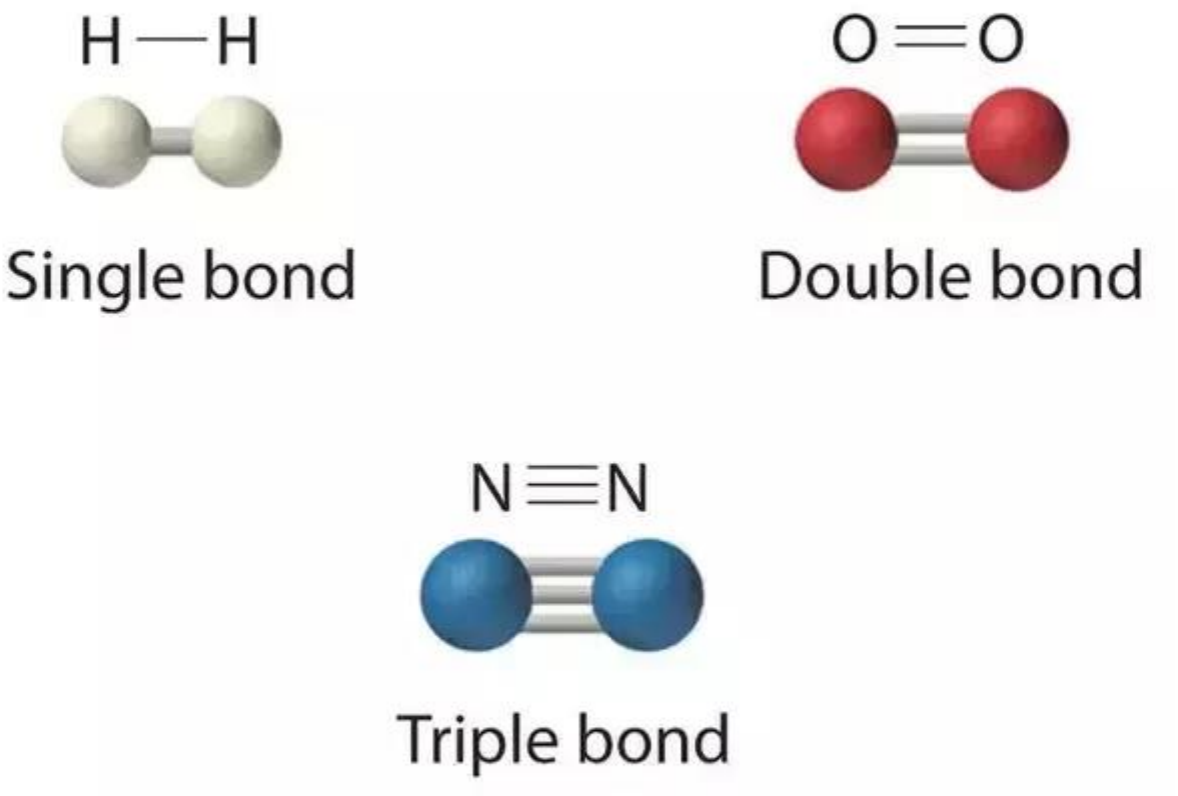


Atomic Bonds (Primary bond)

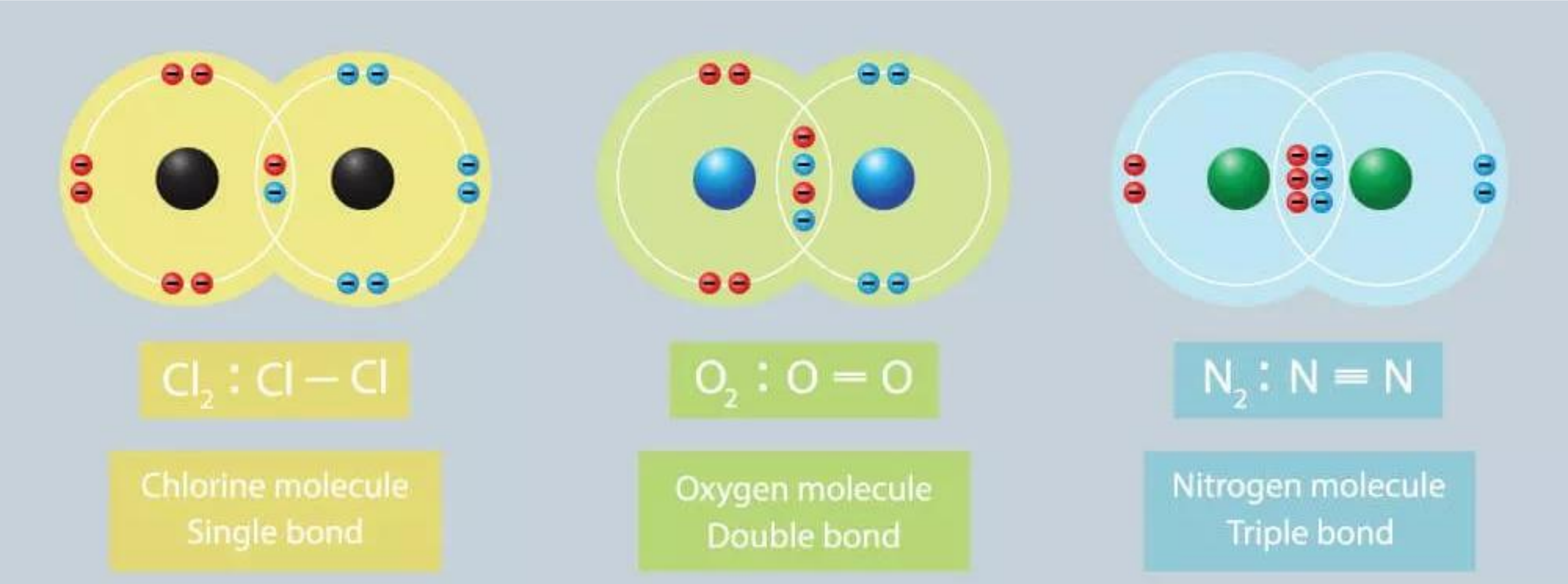
Single bond (e.g. CH_3-CH_3)

Double bond (e.g. $CH_2 = CH_2$)

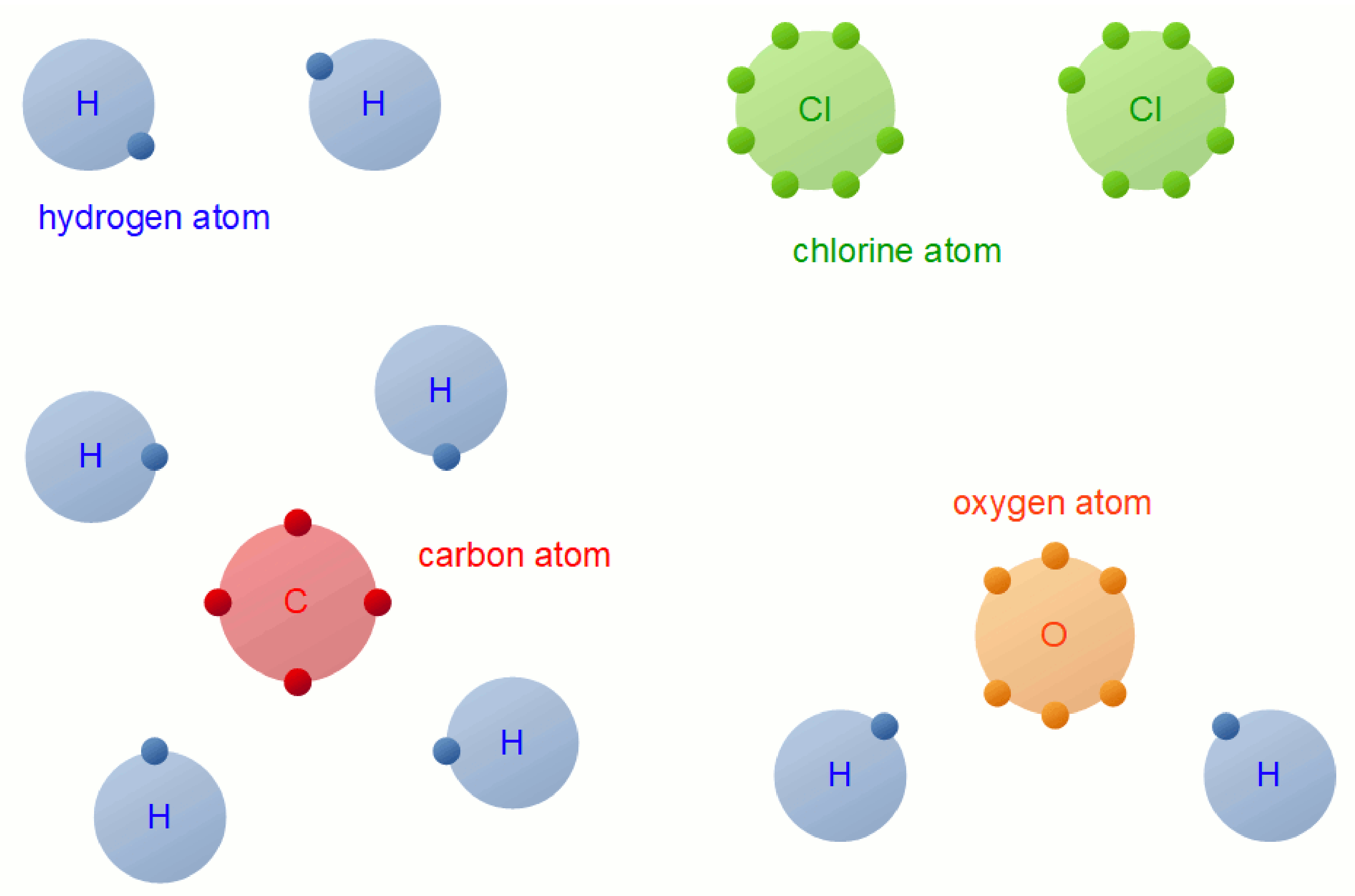
Triple bond (e.g. $CH \equiv CH$).



Atomic Bonds (Primary bond)



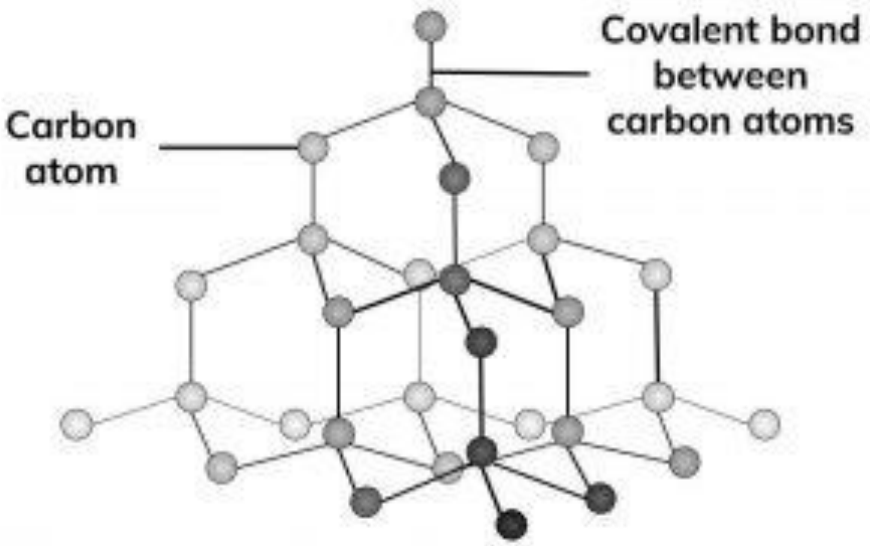
Atomic Bonds (Primary bond)

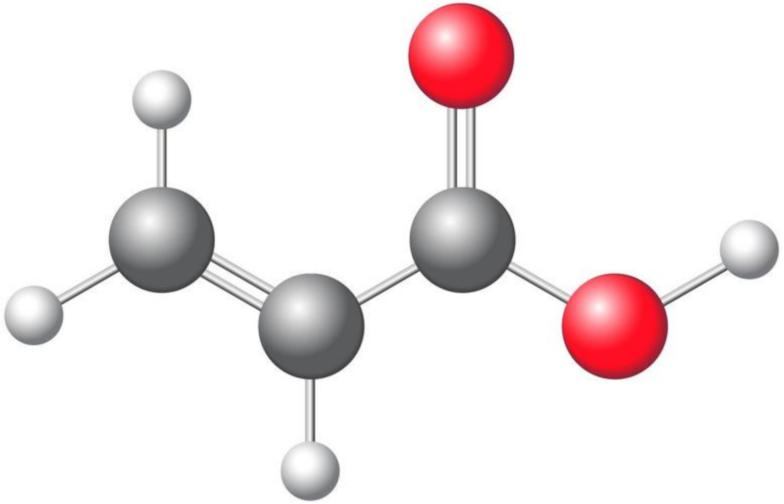


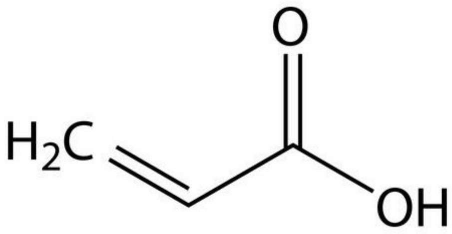
Atomic Bonds (Primary bond)

Examples:

Basic bond of diamond & polymer







Atomic Bonds (Primary bond)

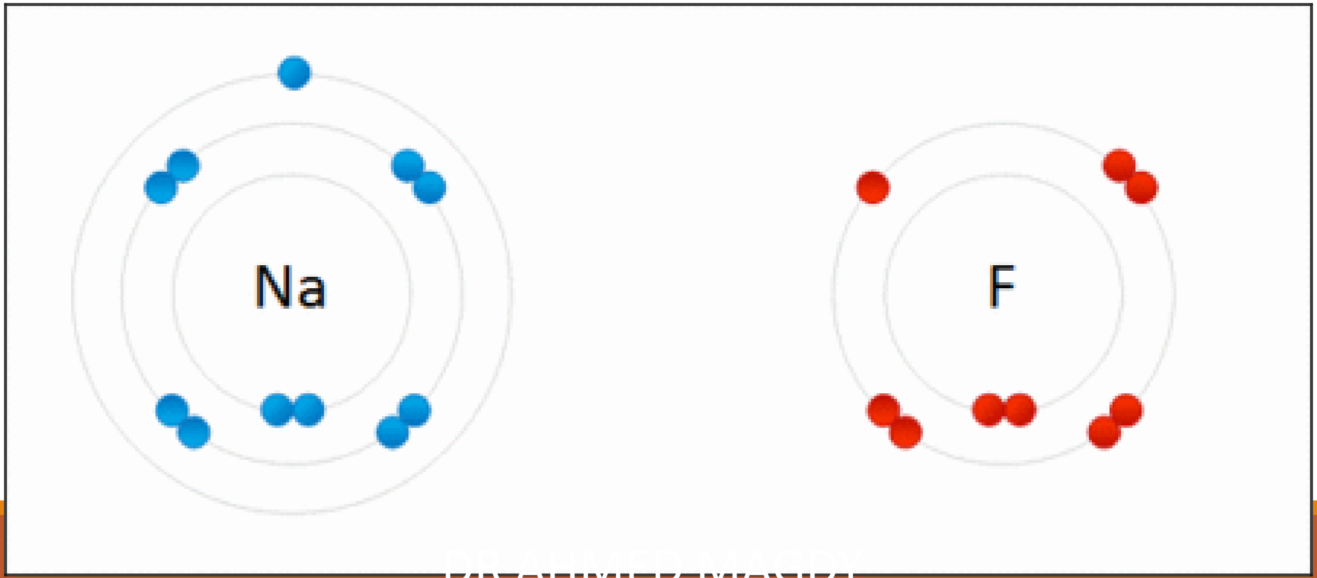
Characteristics of covalent bond:

1. Highly directional bond.
2. High strength and hardness.
3. High heat resistance.
4. Thermal and electrical insulators.
5. Dissolve in organic solvents.

Atomic Bonds (Primary bond)

Occurs by:

1. Electron transfer from one atom (become +ve ion)
2. To another (Become –ve ion)
3. Electrostatic attraction occurs between them.



Atomic Bonds (Primary bond)

Sodium gives his outer electron to Chlorine ➲ Na^{+} Cl^{-}.

Examples: Basic bond for Ceramics, Glasses.

Atomic Bonds (Primary bond)

Characteristics of Ionic bond:

1. Spherical in nature.
2. High strength and hardness.
3. High heat resistance.
4. Insulators as solids.
5. Electric conductors in solutions.
6. Dissolve in ionizing solvents (not in organic solvents).

Atomic Bonds (Primary bond)

Metallic bond

The metals have loosely held valence electrons, so they move freely between atoms forming *cloud of electrons*.

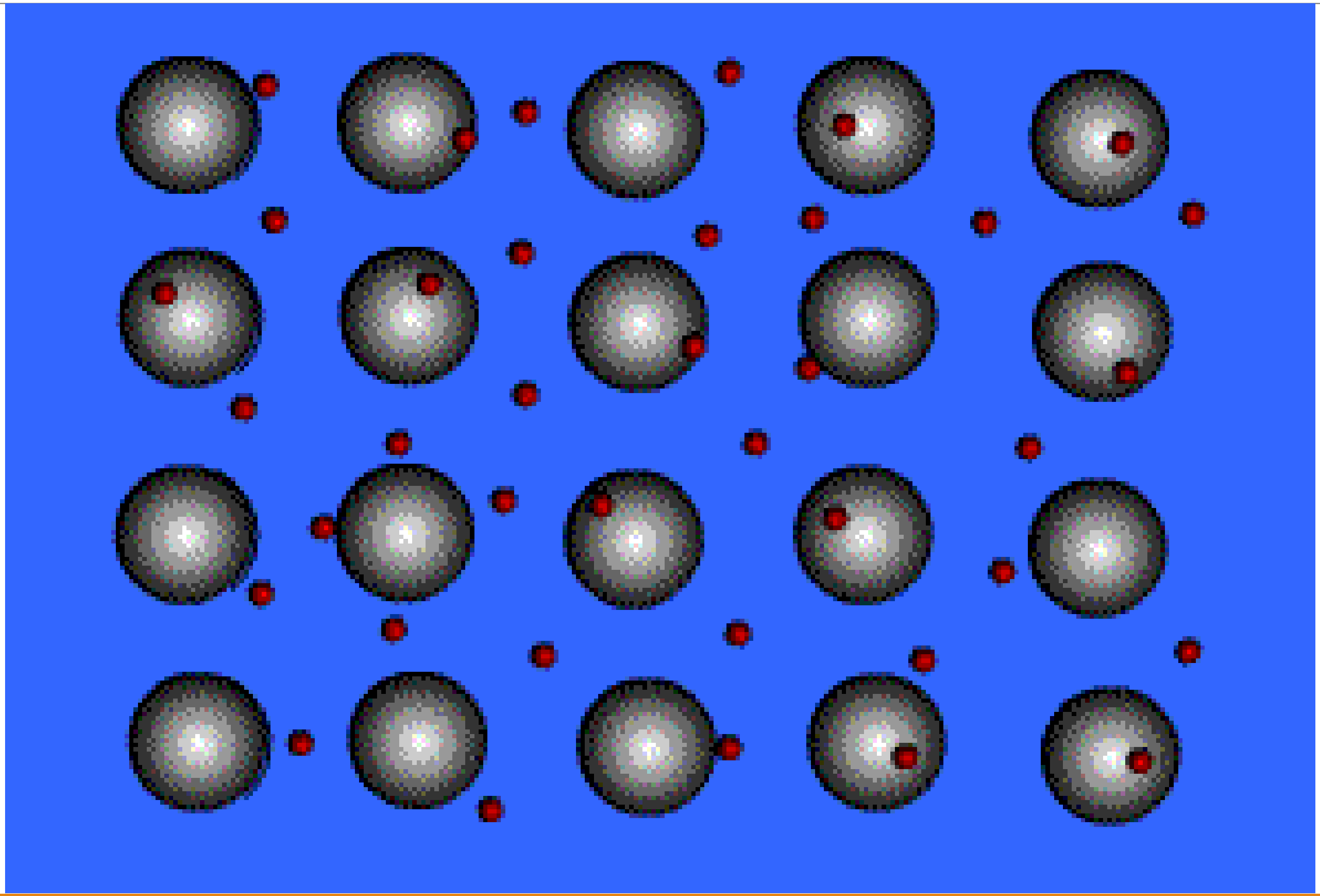
Atomic Bonds (Primary bond)

Metallic bond

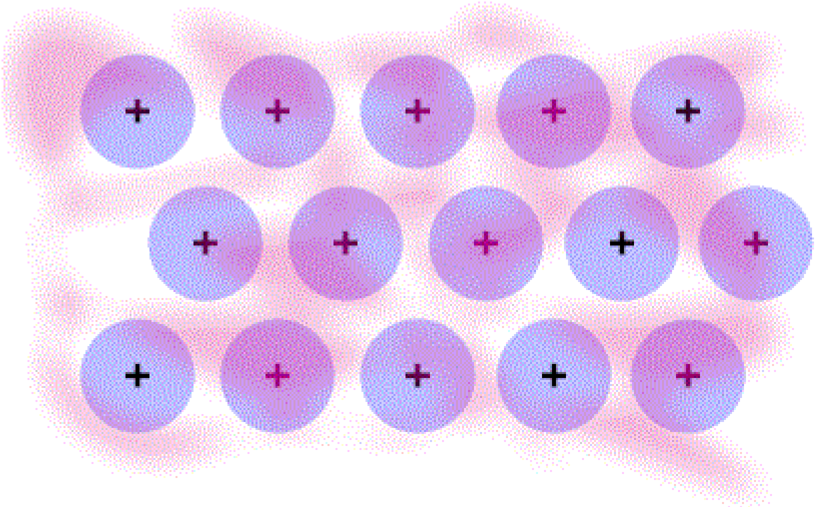
So the metallic bond results from the attraction between consisting

+ve ion cores and the surrounding cloud of free electrons.

Atomic Bonds (Primary bond)



Atomic Bonds (Primary bond)



Atomic Bonds (Primary bond)

Characteristics of Metallic bond:

1. High strength and hardness.

2. High thermal resistance.

Atomic Bonds (Primary bond)

Characteristics of Metallic bond:

3. High thermal conductivity (as free electrons conduct heat).
4. High electric conductivity (as free electrons carry the electricity).
5. Opaque (as free electrons absorb light).
6. Lustrous (as free electrons reflect the light).

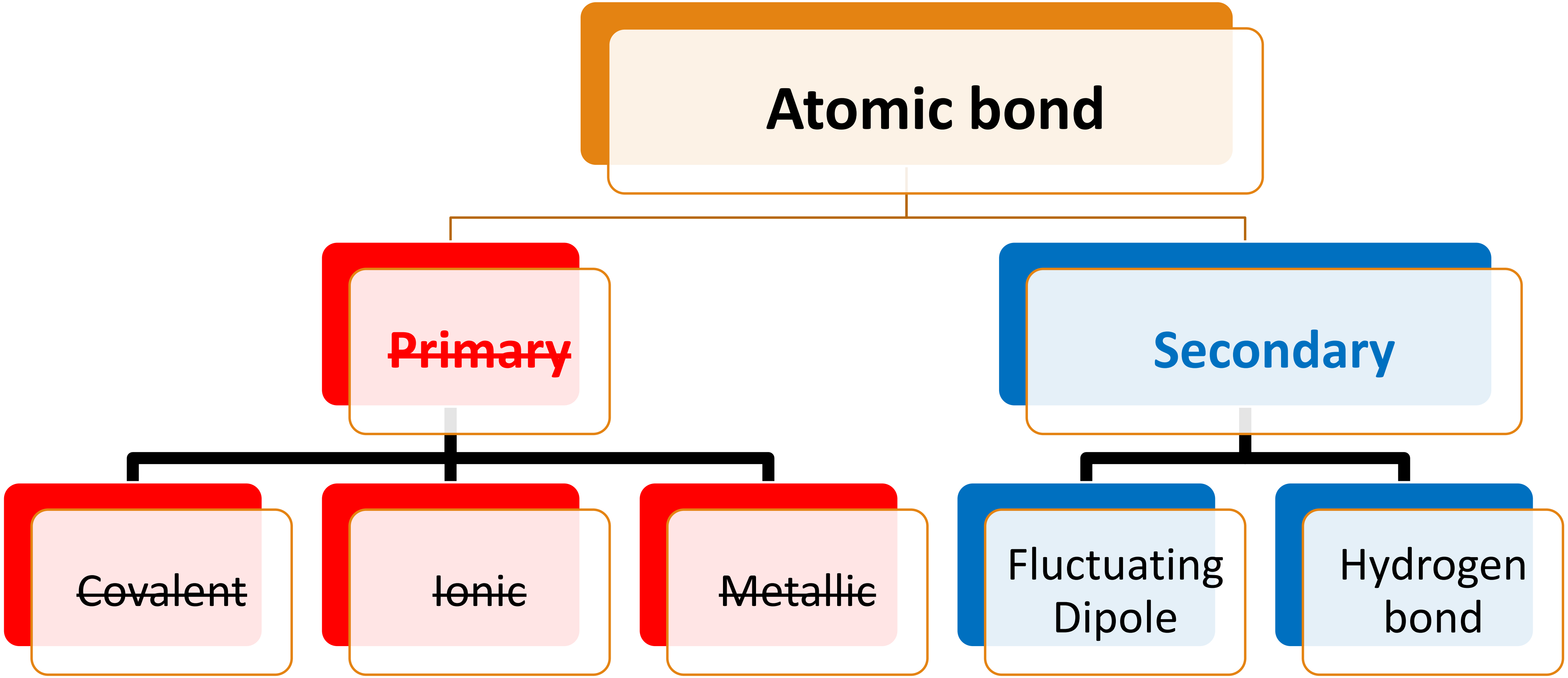
Atomic Bonds (Primary bond)

Characteristics of Metallic bond:

7. Leads to crystalline arrangement in metals

8. Leads to easy of deformability of metals.

Atomic Bonds



Atomic Bonds (Secondary bond)

Fluctuating Dipole:

- It developed between atoms due to asymmetry of electron distribution.
- This asymmetry gives the atom dipole character.
- It is a temporary bond.

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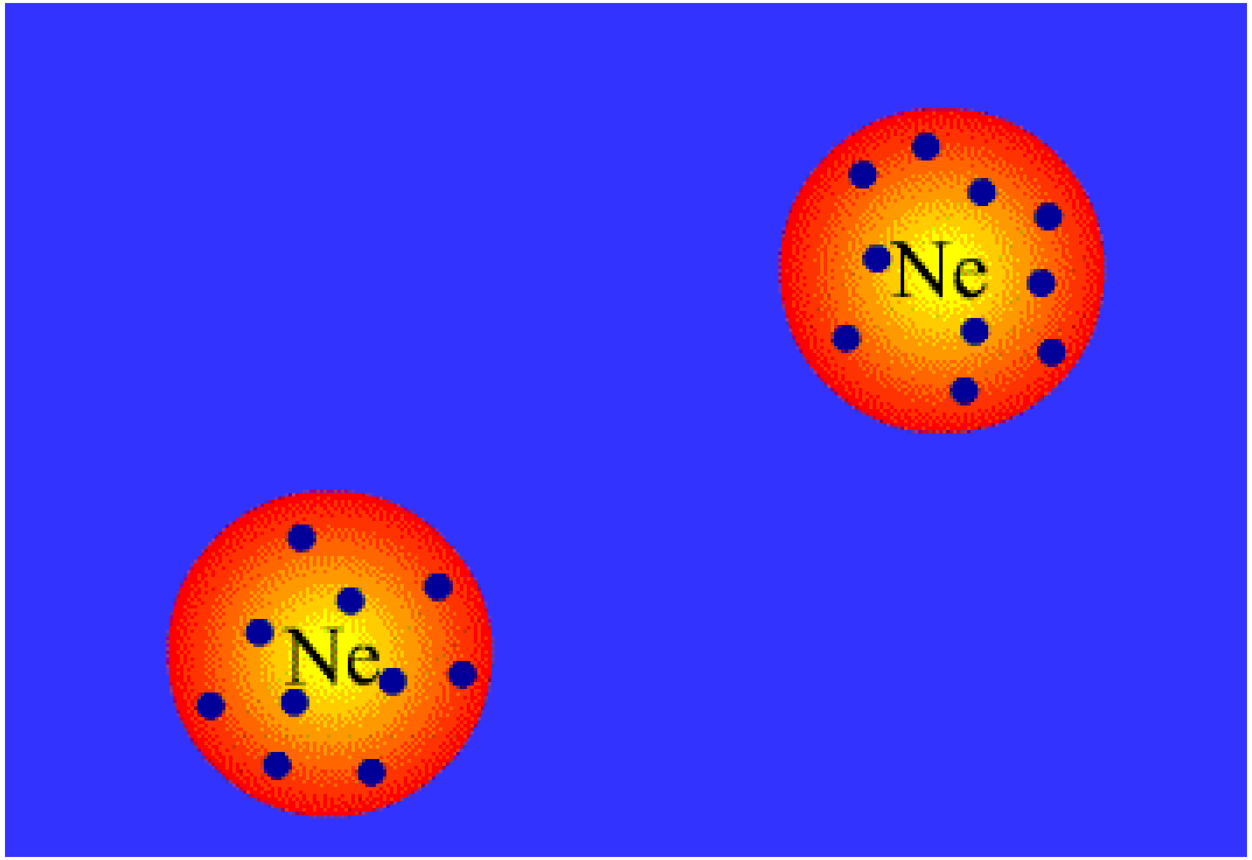
Atomic Bonds (Secondary bond)

Fluctuating Dipole:



Atomic Bonds (Secondary bond)

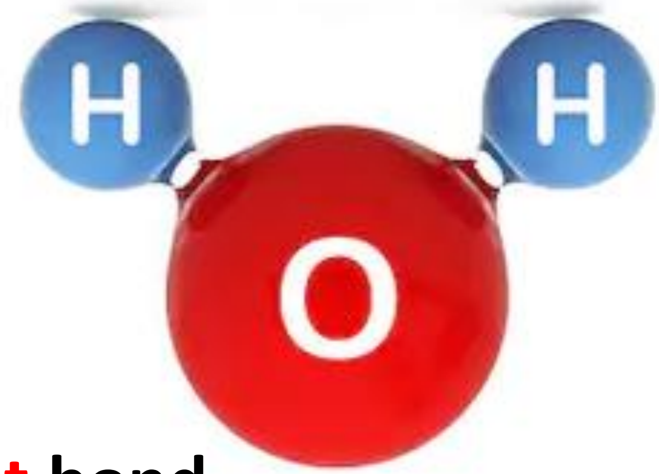
Hydrogen bond:

It developed between molecules when each molecule has a dipole.

Atomic Bonds (Secondary bond)

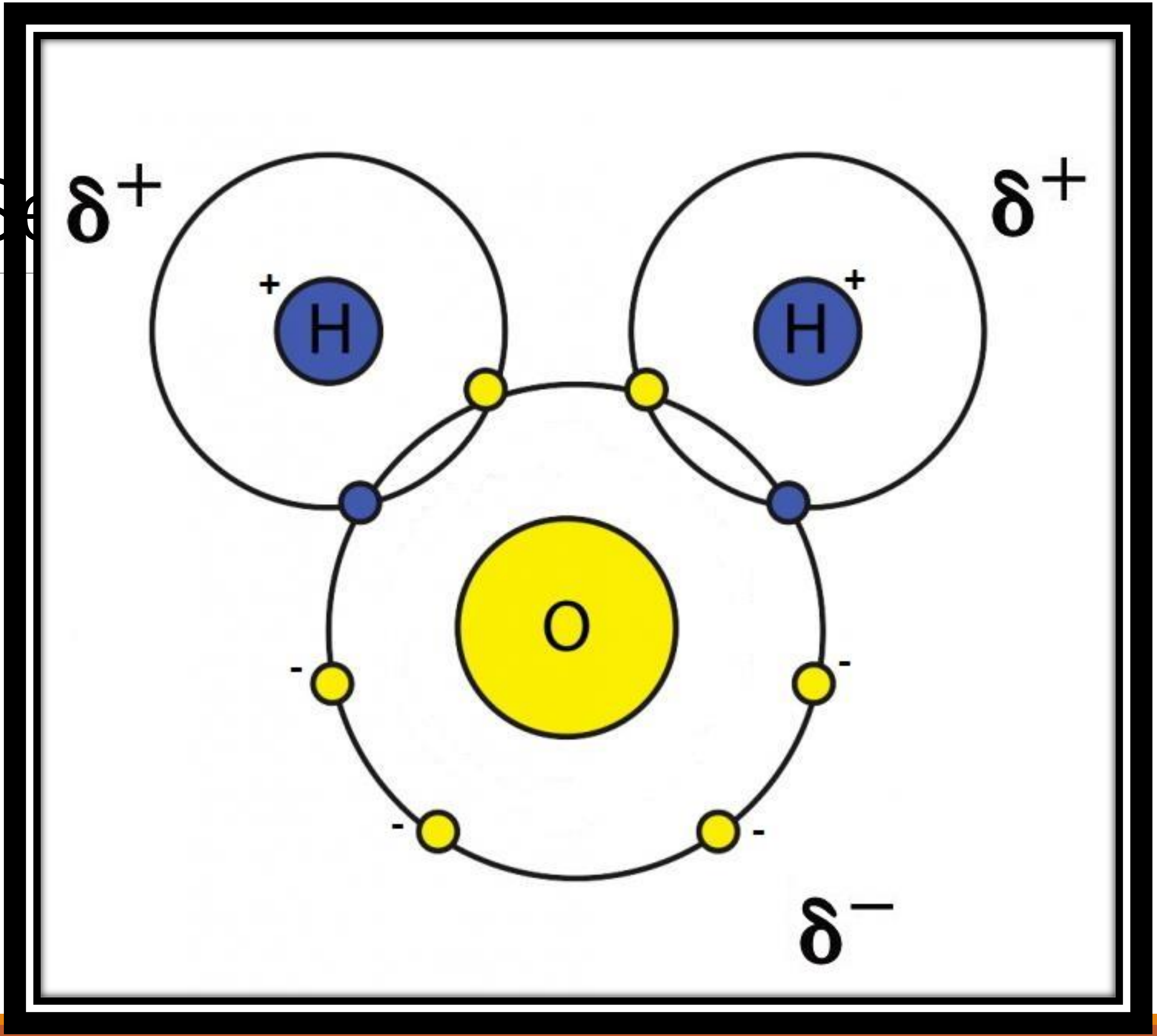
Hydrogen bond:

Highly directional Covalent bond



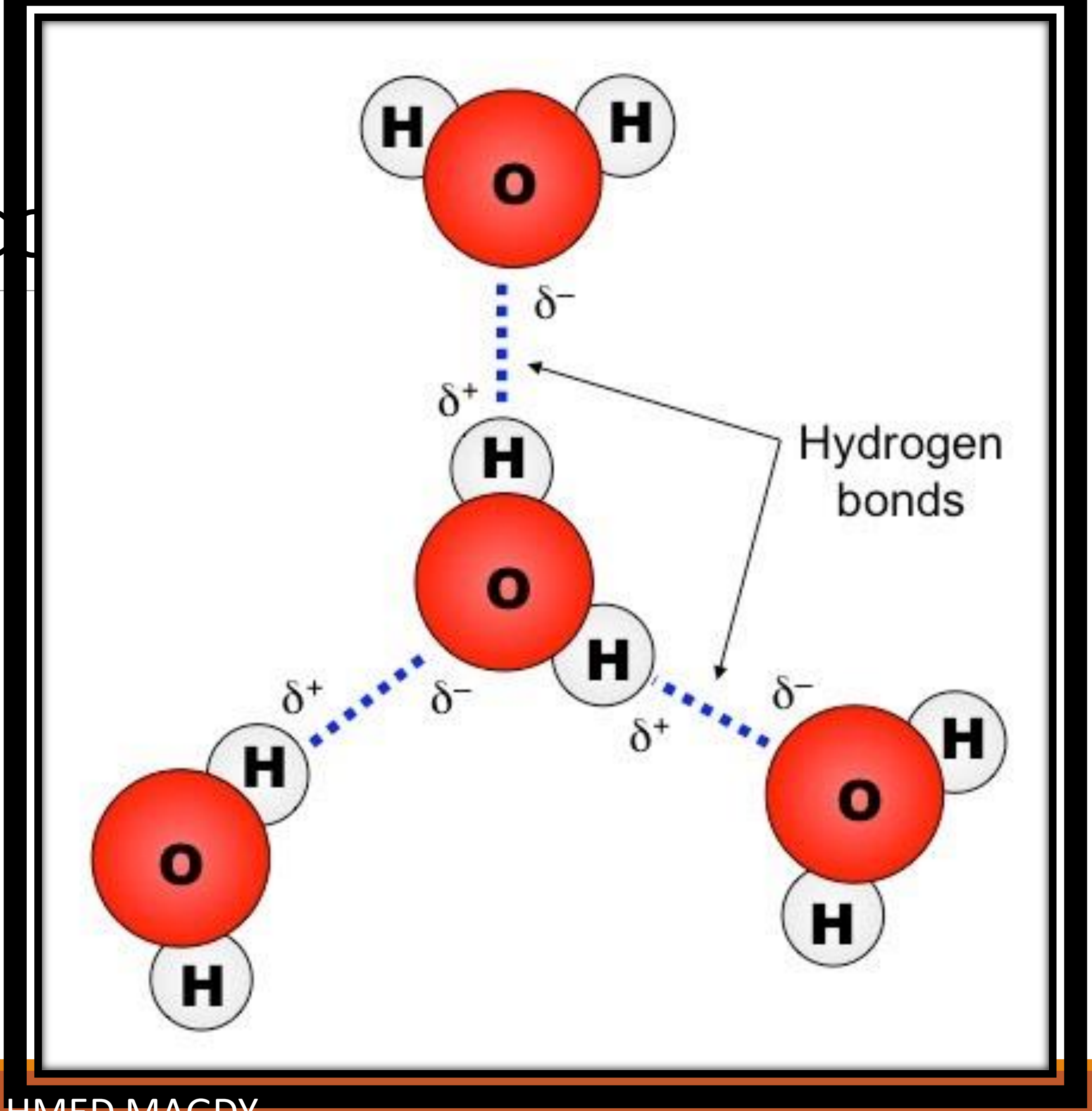
Atomic Bonds (Se

Hydrogen bond:



Atomic Bonds (Sec

Hydrogen bond:



Atomic Bonds (Secondary bond)

Characteristics of secondary bond:

1. Low strength and hardness.
2. Low heat resistance.
3. High thermal expansion.

Inter-atomic Distance

It is the distance between atoms.

Resulted from 2 equal but opposite forces:

1. Repulsive forces → due to electrostatic field of each atom.
2. Attractive forces → different types of atomic bonds.

Inter-atomic Distance

Factors affecting interatomic Distance:

1. Temperature
2. Number of adjacent atoms:
3. Type of the bond:
4. External forces

Inter-atomic Distance

Factors affecting interatomic Distance:

1. <u>Temperature</u>

Heat increases I.A.D (as it increases energy of atoms)

Inter-atomic Distance

2. <u>Number of adjacent atoms:</u>

More adjacent atoms will increase I.A.D (as less specific attraction to any neighboring atom).

Inter-atomic Distance

3. **Type of the bond:**

Increase number of shared electrons in covalent bond will decrease I.A.D (as it is means more strong bond).

$CH \equiv CH$ is stronger than $CH_2 = CH_2$, stronger than $CH_3\text{-}CH_3$.

Inter-atomic Distance

4. **Any external forces**

May displace atoms and change I.A.D.

Classification of Solids

According to intermolecular bond:

Bond between atoms = inter-atomic bond = intra-molecular bond

Must be primary bond

Bond between molecules= inter-molecular bond

May be primary or secondary

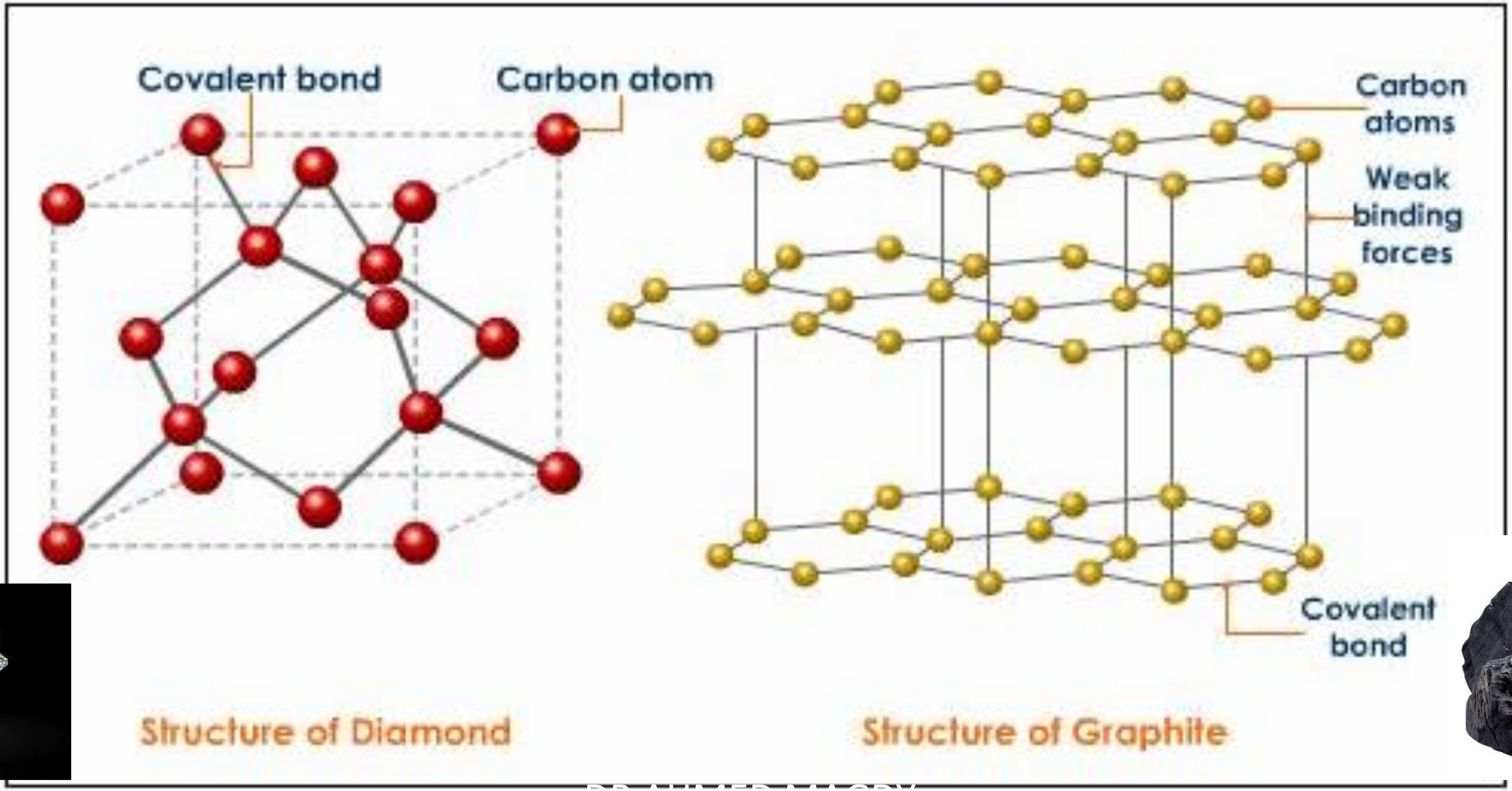
Intra جوة

Inter بين

Classification of Solids

	Atomic Solids	Molecular Solids
Bonds between atoms	Primary	Primary
Bonds between molecules	**Primary**	**Secondary**
Properties	**High** strength and hardness	**Low** strength and hardness
Example	Diamond	Polymers

Classification of Solids



Classification of Solids

According to Arrangement of Atoms:

Amorphous

Crystalline

Classification of Solids

Amorphous Solids	Crystalline Solids
Atoms are randomly distributed or with very short arrangement	Atoms are regularly arranged with repetition in 3D (called space lattice or crystal lattice)

Classification of Solids

Amorphous Solids	Crystalline Solids
Have high internal energy	Have low internal energy

Classification of Solids

Amorphous Solids	Crystalline Solids
Have no definite melting temperature (gradually soften by heating and gradually harden by cooling) **Glass Transition temperature:** The temperature at which the amorphous solids start to soften or harden	Have definite melting temperature

Classification of Solids

Amorphous Solids	Crystalline Solids
Examples: Wax, Glass	Metals

Crystalline Solids:

The atoms arrange themselves in a repeated manner.

The smallest repeated unit in a crystal lattice is called unit cell.

Unit cell may be one of 7 main patterns and subdivided to make 14 possible patterns.

Crystalline Solids:

Cubic System:

Axes: a = b = c

Angles between axes: 90^{o}

It is subdivided into:

1. Simple cubic system
2. Body centered cubic
3. Face centered cubic

Cubic system

Simple cubic system	Body centered cubic	Face centered cubic
8 atoms at the corner	8 atoms at the corner + One atom at the center	8 atoms at the corner + One atom at each face
1 atom (8 x 1/8)	2 atoms (8 x 1/8) + 1	4 atoms (8 x 1/8) + (6 x 1/2)

Crystalline Solids:

Hexagonal System:

Axes: a = b ≠ c

Angles between axes: $\alpha = \beta = 90^o$, g = 120^o

It is subdivided into:

1. Simple hexagonal system
2. Hexagonal closed packed

Crystalline Solids:

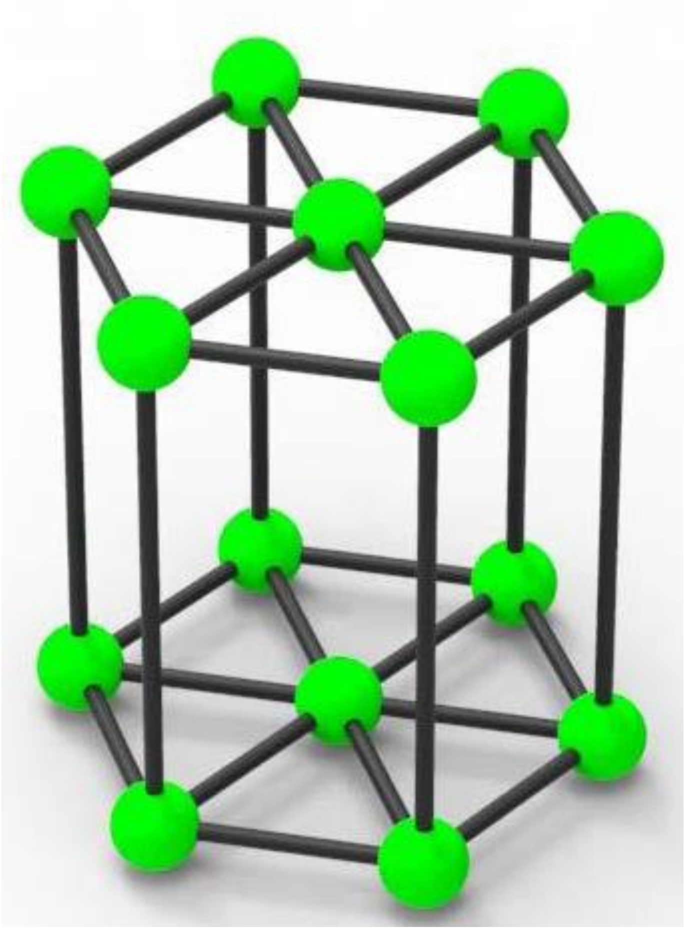
Hexagonal System:

Axes: $a = b \neq c$

Angles between axes: $\alpha = \beta = 90^o$, $g = 120^o$

It is subdivided into:

1. Simple hexagonal system
2. Hexagonal closed packed



Crystalline Solids:

Simple Hexagonal System	Hexagonal closed Packed
6 atoms at the top (6 x 1/6)	6 atoms at the top (6 x 1/6)
6 atoms at the bottom (6 x 1/6)	6 atoms at the bottom (6 x 1/6)
One at the upper face (1 x ½)	One at the upper face (1 x ½)
One at the lower face(1 x ½)	One at the lower face (1 x ½)
	3 atoms at the center
1 + 1 + ½ + ½ 3 atoms	1 + 1 + ½ + ½ + 3 6 atoms

Atomic Packing Factor

It is the fraction of space occupied by the atoms

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

Simple cubic system = 0.54.

Body Centered Cubic = 0.68.

Face Centered Cubic = 0.74.

Hexagonal Closed Packed = 0.74.

Atomic Packing Factor

Clinical importance:

Materials with ↑ APF ➲ have ↑ densities and strength properties.

Imperfections of Crystalline System

Theoretical calculation of strength is much higher than actual strength.

This is due to the presence of defects in the crystalline system

Imperfections of Crystalline System

Types of Crystalline Defects:

1. Point defect.
2. Line Defect.
3. Plane Defect.

Imperfections of Crystalline System

1. Point Defects:

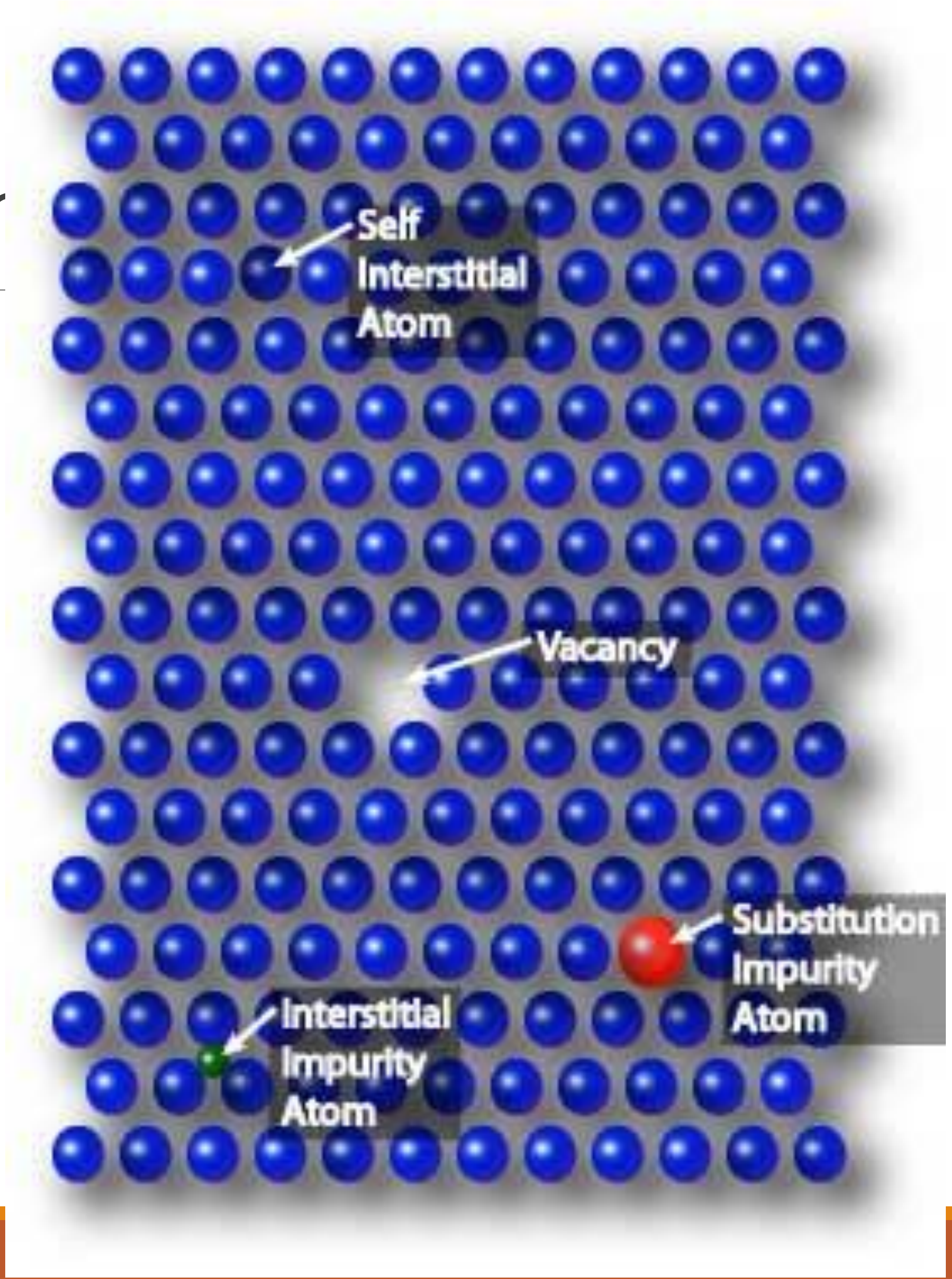
   a) Vacancy → missing atom.

   b) Self interstitial atom → extra atom from same metal.

   c) Interstitial impurity → extra atom from another metal.

   d) Substitutional impurity → replaced atom from another metal.

Imperfections of Crystallir



Imperfections of Crystalline System

2. Line Defects:

It is the most common type.

Dislocation:

It is the displacement of a raw of atoms from their normal positions in the lattice

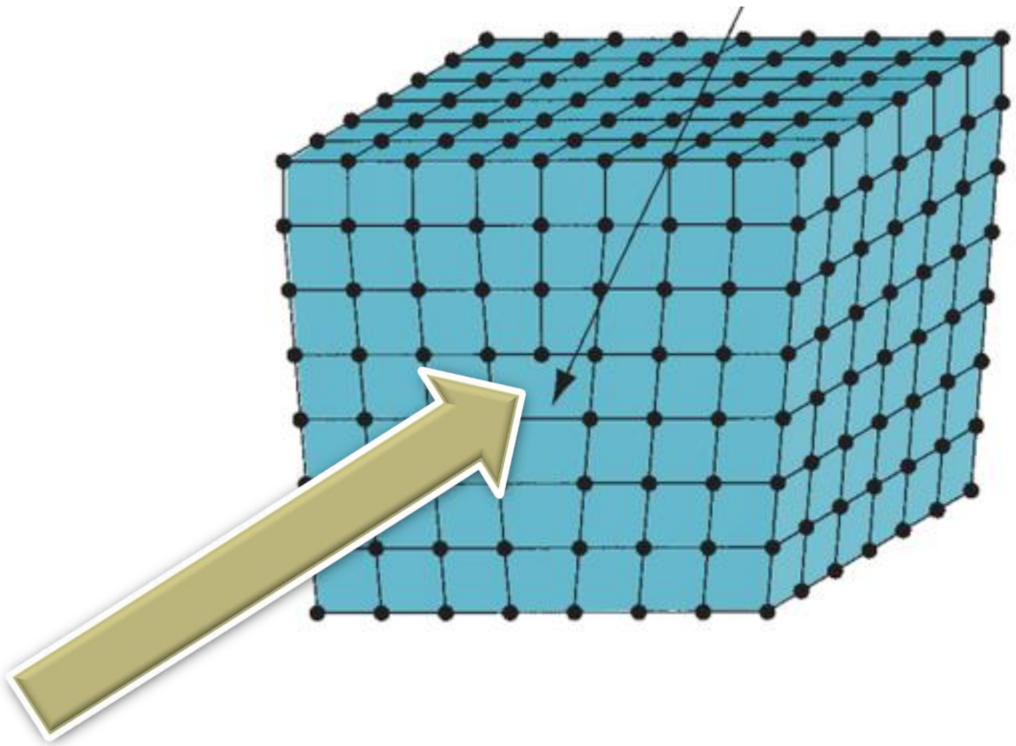
Clinical importance: plastic deformation in metals occurs by motion of dislocations

Imperfections of Crystalline System

2. Line Defects:

Clinical importance:

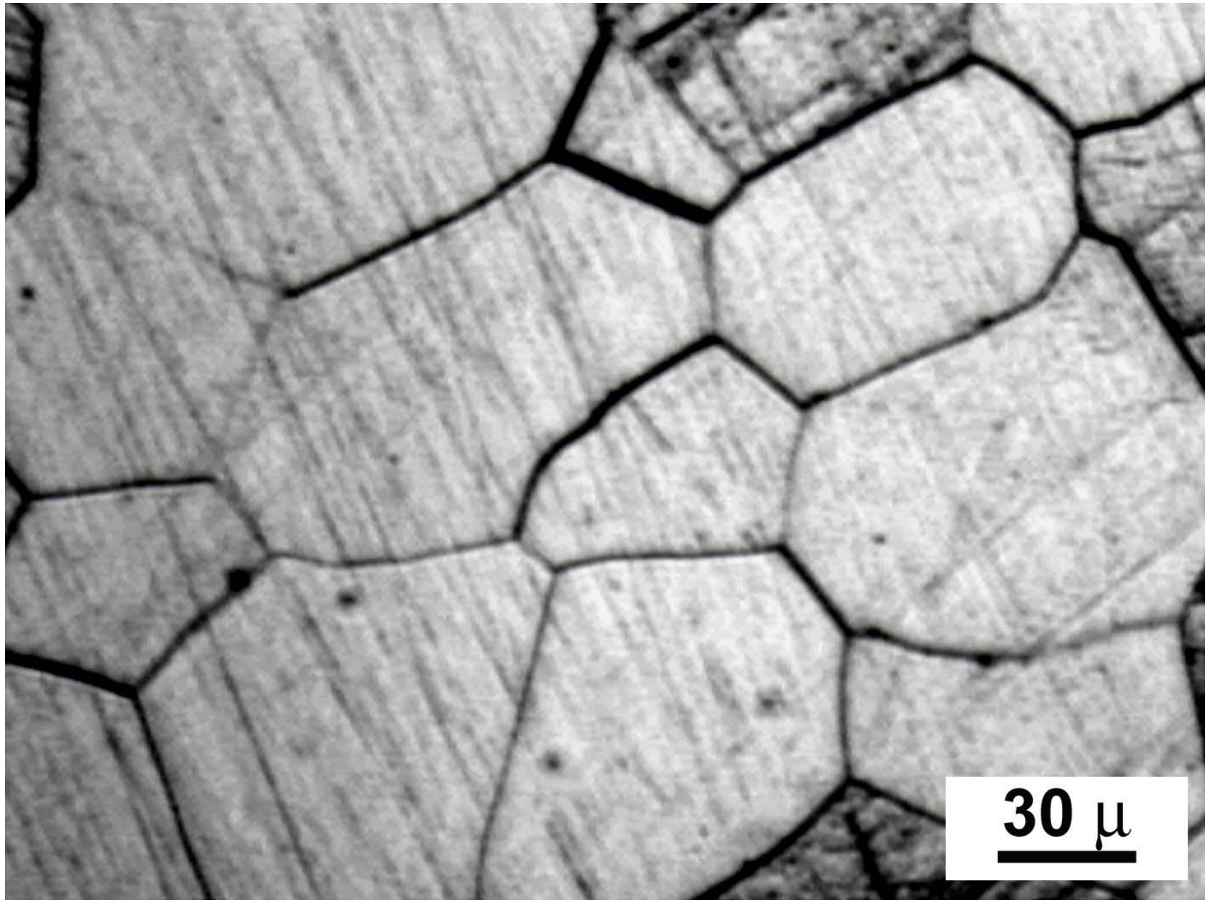
Helps in plastic deformation in metals



Imperfections of Crystalline System

2. Plane (planer) Defects:

Like Grain boundaries.



Polymorphism

Materials that have the same chemical composition but found naturally in different physical forms.

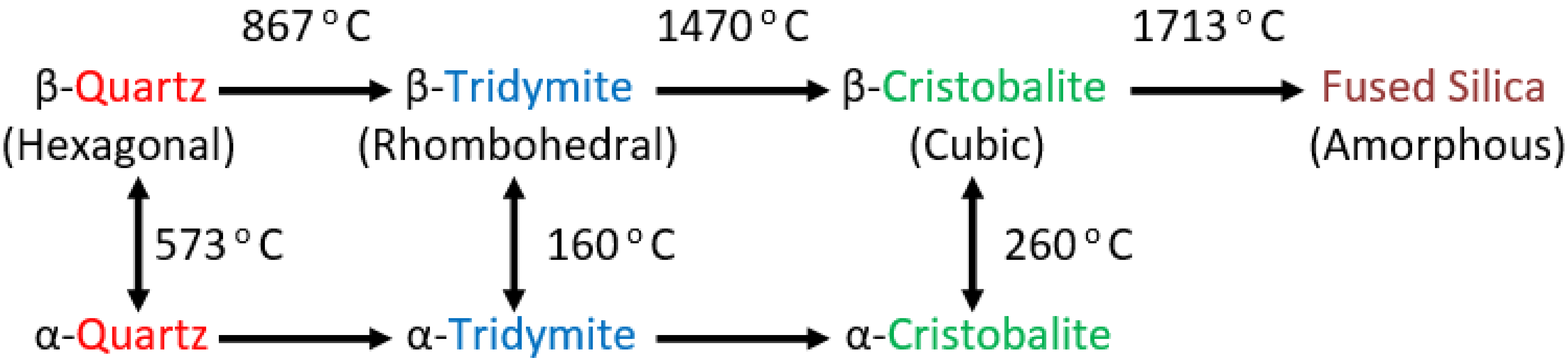
The polymorphic forms have **different physical properties** as density, freezing point, optical properties, conductivities …etc

Polymorphism

If the material is **inorganic**, the polymorphism is called **allotropy.**

If the material is **organic**, the polymorphism is called **isomerism.**

Polymorphism



Polymorphism

Displacive transformation	Reconstructive transformation
No breakdown of atomic bonds	Breakdown of atomic bonds followed by reconstruction of new space lattice
Accompanied by expansion	No Expansion
Rapid transformation	Slow transformation
Occurs at lower temperatures	Occurs at higher temperature

Correlation Between Atomic Structure and Materials Properties:

1. **Density:**

Controlled by:

a) Atomic weight.
b) Atomic radius.
c) Atomic packing factor.

Correlation Between Atomic Structure and Materials Properties:

2. **Bond strength leads to:**
   a) High strength and hardness.
   b) High melting and boiling temperature.
   c) Low coefficient of thermal expansion.

Correlation Between Atomic Structure and Materials Properties:

3. Electrical and Thermal conductivity:

Depends on nature of atomic bond

a) Metallic solids conduct heat and electricity.
b) Ionic solution conduct electricity, while ionic solids are electrical insulators.
c) Covalent solids are insulators.

Correlation Between Atomic Structure and Materials Properties:

4. Crystalline solids have low internal energy

Because they send their internal energy in arranging their atoms.

Correlation Between Atomic Structure and Materials Properties:

5. FCC is more ductile than BCC due to higher atomic packing factor.

Correlation Between Atomic Structure and Materials Properties:

6. FCC is more ductile than HCP due to symmetry of the cubic system.

Thank You