Types of solids

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OBJECTIVES

- Describe the general properties of a solid.
- Describe the six different types of solids.
- The goal is for the students to explore solid materials and to understand this state of matter. A variety of different objects will be used to demonstrate the properties of solids.

Introduction:

- Solid-state is nothing but one of the states of matter.
- The matter exists in three states – solid, liquid and gas.
- The liquid and gas are fluids because of their ability to flow.
- The fluidity in both of these states is due to facts that the molecules are free to move.
- The free mobility of the molecule is due to weak intermolecular forces.

- The constituents particles in solids have fixed positions and can only oscillate about their mean positions. This explain the rigidity in solids. It is due to strong intermolecular forces.

- A solids may be defined as a form of matter in which the ions, atoms or molecules are held strongly that they cannot easily move away from each other. Hence solids is rigid form of matter which has a definite shape and a definite volume.

General Characteristics of Solids

i. Solids have definite mass, volume, shape and density. Usually, the density of solid state is greater than the density of liquid and gaseous state. Water and mercury are exceptions. The density of ice (solid state of water) is lower than the density of liquid state of water. The density of mercury (which exists in liquid state) is very high (13.6 g mL^{-1}).

ii. Solids are usually hard, incompressible and rigid. Some solids like sodium, potassium and phosphorous are exceptions; they are soft. Solids cannot be compressed because the intermolecular distance of separation between neighbouring molecules is very small.

iii. In a solid state, intermolecular forces of attraction between the constituent particles are stronger than those present in liquid and gaseous states.

iv. All pure solids have characteristic melting points which depend on the extent of intermolecular forces present in the solid state. Stronger the intermolecular forces of attraction, higher is the melting point of the solid. Weaker the intermolecular forces of attraction, the lower is its melting point. Hence, depending on the intermolecular forces of attraction, melting points of the different solids range from almost absolute zero (helium) to a few thousand Kelvin (diamond).

v. The intermolecular forces of attraction hold the constituent particles of the solids tightly. Hence the particles cannot change their positions and remain stationary at one position. Therefore, solids cannot flow like liquids.

Types of Solid

Based on the arrangement of constituent particles, solids are classified into two-state types:

- ❑ Crystalline Solids

- ❑ Amorphous Solids

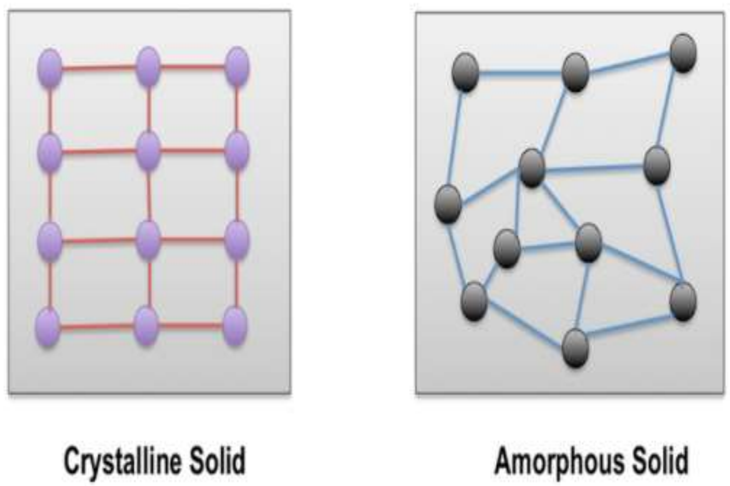
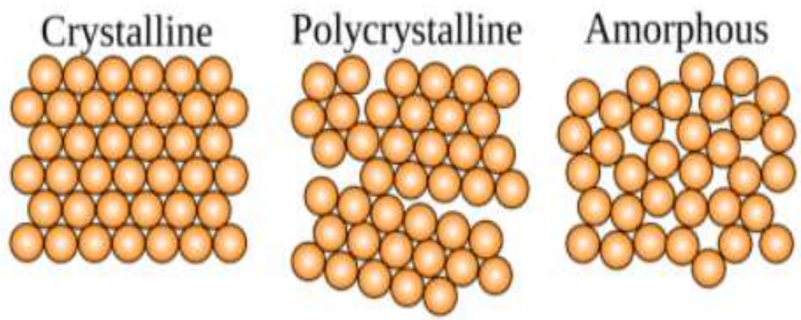


Image 1: Arrangement of Atoms



Crystalline Solids

The solids in which the constituent particles of matter are arranged and organized in a specific manner are called **Crystalline Solids**. These solids contain crystals in their structure and each crystal has definite geometry. Adding further, as crystalline solids have low potential energy, they are the most stable form of solids. Almost all solids fall in the category of crystalline solids including metallic elements (iron, silver, and copper) and non-metallic elements (Phosphorus, Sulphur, and iodine). Also several compounds like sodium chloride, zinc sulphide and naphthalene build crystalline solids.

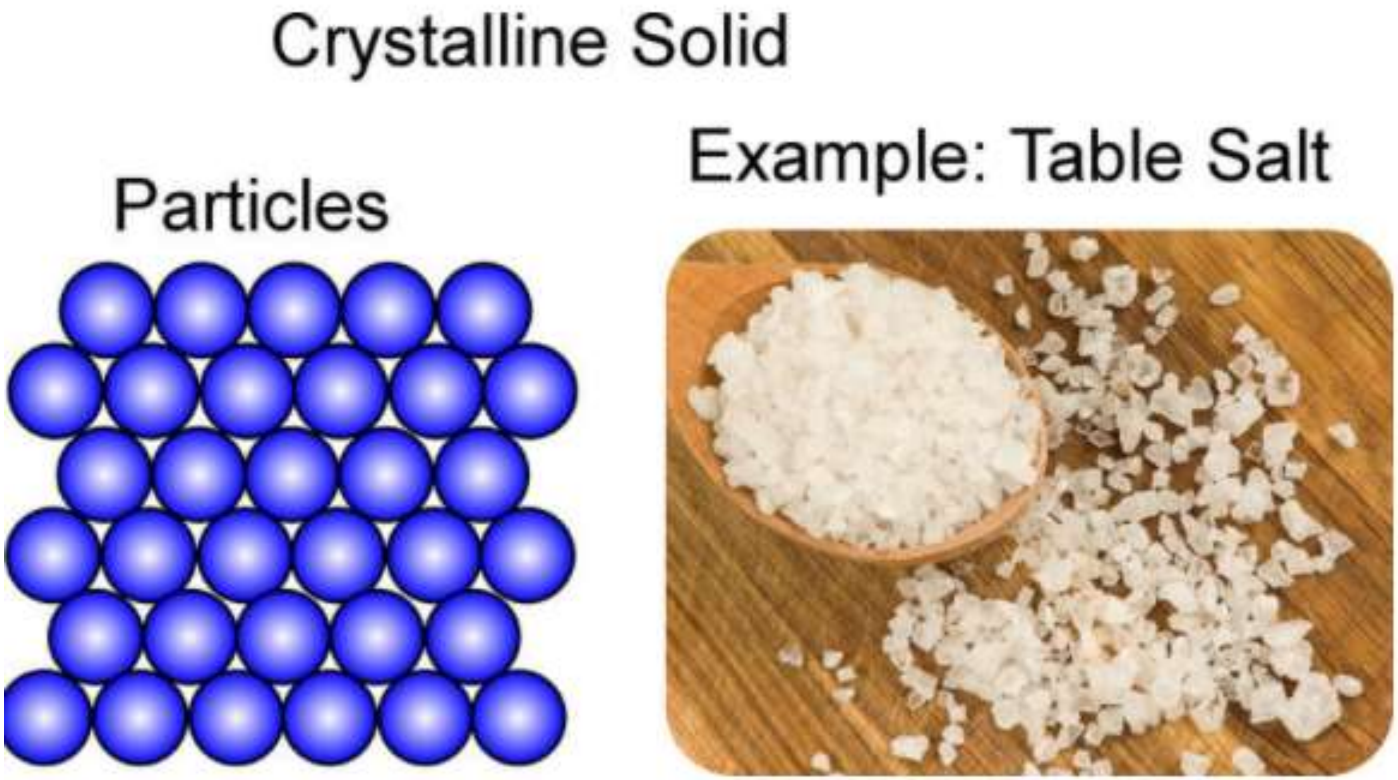


Image 2: Example of Crystalline Solids

Characteristics of Crystalline Solids

The main characteristics of crystalline solids are mentioned as below:

- ❖ Crystalline solids show regular structure and have definite geometrical shape.
- ❖ The sharp freezing point is found in crystalline solids. This is because the distance between same atoms/molecules or ions is same and remains constant, unlikely from amorphous solids.

- The heat of fusion is definite and fixed as the regularity in crystal lattice remains same and is ideal.
- Crystalline Solids are also known as **True Solids** as they don't tend to flow like pseudo solids.
- When we cut a crystal solids with a knife, we obtain a flat and smooth surface.
- The nature of crystalline solid is anisotropic; that is, the properties turn out to be different in different direction.
- Crystalline solids depict both long range and short range order.

Examples: Quartz, Calcite, Sugar, Mica, Diamonds etc.

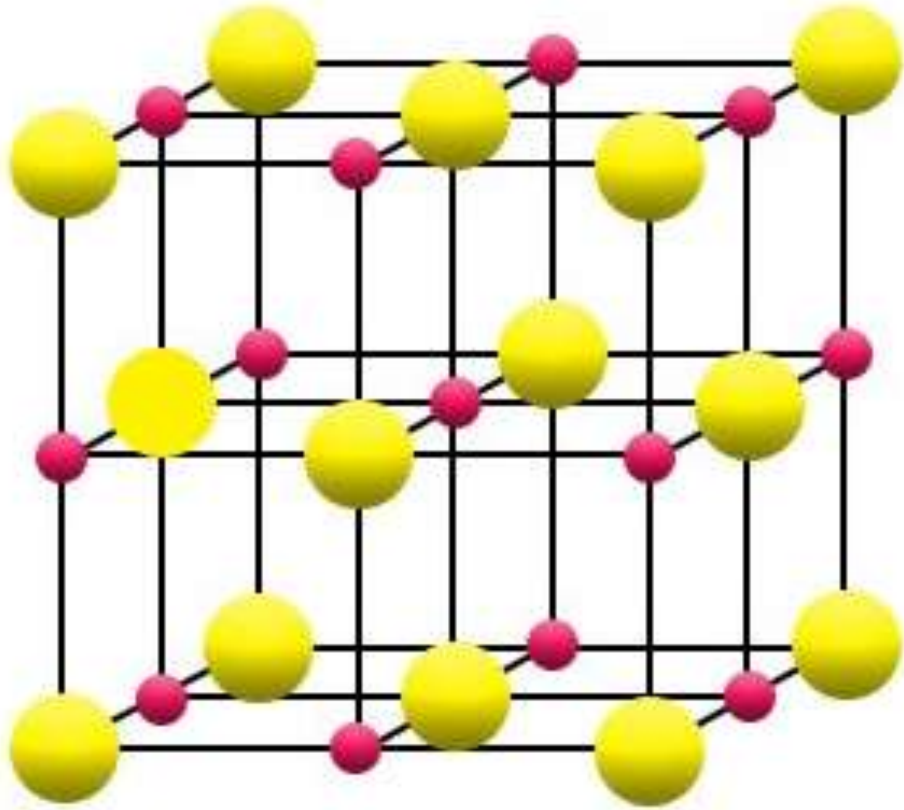


Image 3: Lattice Structure of Crystalline Solids

Uses of Crystalline Solids

There are many applications of crystalline solids, some are:

- Diamond is the most decent example of crystalline solids and is widely used in making beautiful jewelry items.
- Quartz is extensively used in manufacturing of watches and clocks.
- Many crystalline solids are used as a raw material in many industries

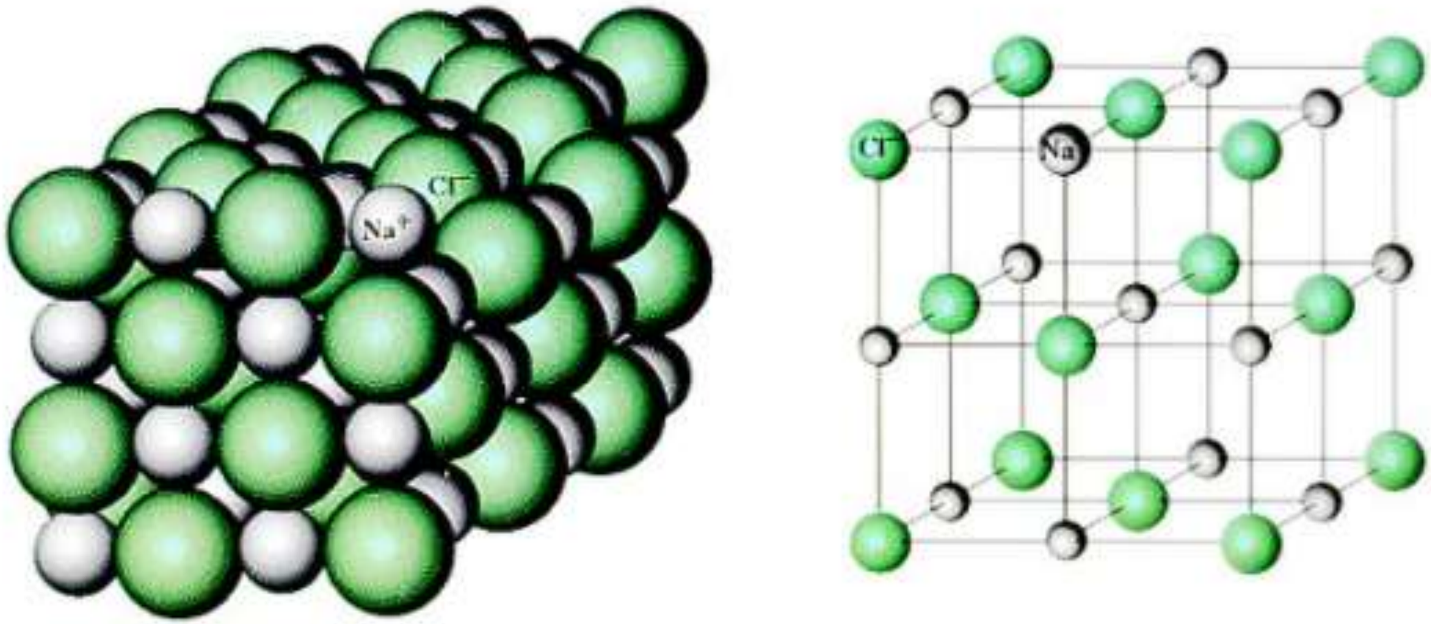


Image 4: Structure of NaCl

Amorphous Solids

The solids in which the constituent particles of matter are arranged in a random manner are called amorphous solids. It is a non-crystalline solid with no proper arrangement of atoms in the solid lattice. In other words, we can define amorphous solids as materials which don’t have certain organized arrangement of atoms and molecules. Most solids are amorphous in nature and are utilized in many sectors as well. One of the most common examples of amorphous solids is glass, which is used widely in the manufacturing sector.

Characteristics of Amorphous Solids

An Amorphous Solid depicts following properties, which are as follows:

- ❖ The constituent particles of matter inside solid are arranged in a random manner, that is, the position of atoms and molecules is not fixed and varies from one solid to another.
- ❖ Amorphous Solids don’t have definite shape or geometry due to random arrangement of atoms and molecules inside the solid lattice.
- ❖ Short-range order is found in amorphous solids

- Amorphous Solids are also called **Pseudo solids** or **Super cooled Liquids** because they don’t form crystalline structure and has the ability to flow.
- The nature of amorphous solids is isotropic in nature that is, the properties measured in all directions come out to be same, example refractive index of amorphous solids is same.
- Amorphous solids don’t show sharp melting point, this is because of irregular packing of amorphous solids

- When we cut an amorphous solid, we find the broken constituent particles to be irregular in shape and geometry.
- Amorphous solids are unsymmetrical in nature, due to irregular packing of atoms and molecules inside the solid lattice.
- Amorphous solids don’t have fixed heat of fusion because of absence of sharp melting point.

Examples: Plastics, Glass, Rubber, Metallic Glass, Polymers, Gel etc.

Uses of Amorphous Solids

There are many applications of amorphous solids, some of them are:

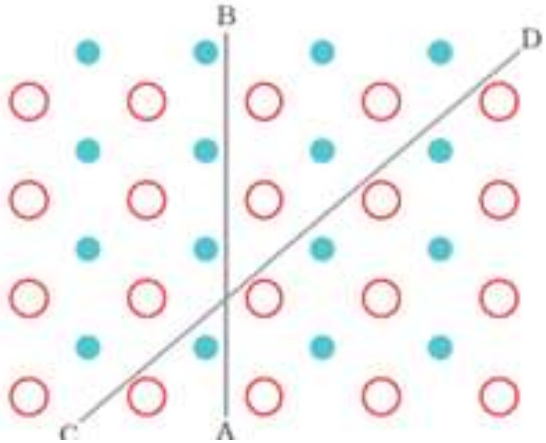
- ✓ The glass is widely used in packaging (food jars, cosmetics box, and soft-drink bottles), making tableware (utensils), in the construction of buildings (windows, lighting, and shelves) etc.
- ✓ Rubber is mainly used in manufacturing of tires, footwear, ropes, camp cloth and as a raw material for several industries.
- ✓ Use of polymer can be seen in manufacturing of pipes, medicines and as a raw ingredient for many factories.
- ✓ Amorphous silicon is considered as the best photovoltaic material to convert sunlight into electricity

Isotropy:

The ability of amorphous solids to exhibit identical physical properties when measured in different directions is called isotropy. This property is due to no long-range order of regular pattern arrangement in them. Thus the arrangement is irregular.

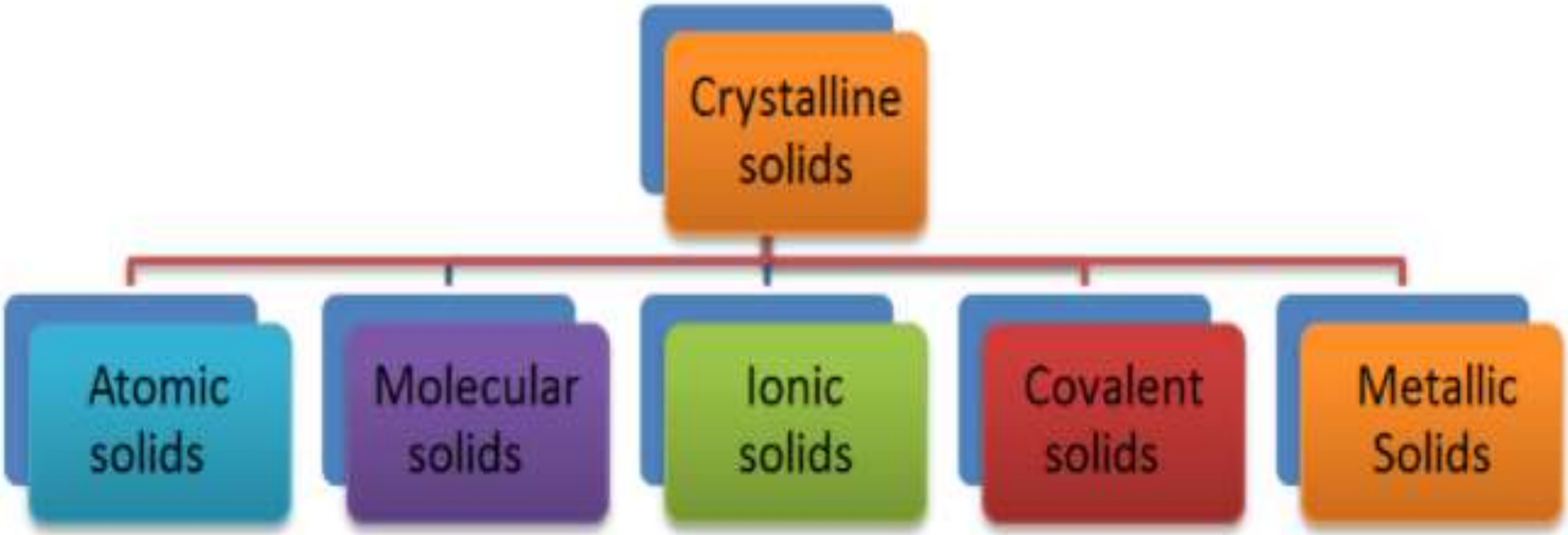
Anisotropy:

The ability of crystalline solids to change their physical properties when measured in different directions is called anisotropy. Some of the physical properties of such solids like electrical resistance or refractive index show different values when measured along different directions in the same crystals. This arises from the different arrangement of particles in different directions.



The electrical resistance of anisotropic solid will be different along line AB and along line CD

Difference between Crystalline and Amorphous	
CRYSTALLINE SOLIDS	AMORPHOUS SOLIDS
Atoms are arranged in regular 3 dimension	They do not have regular arrangement
Sharp melting point	No particular melting point
Anisotropic	Isotropic
True solid	Pseudo solid
Symmetrical	Unsymmetrical
More rigid	Less rigid
Long range order	Short range order
Example: Potassium nitrate, copper	Example: Cellophane, polyvinyl chloride

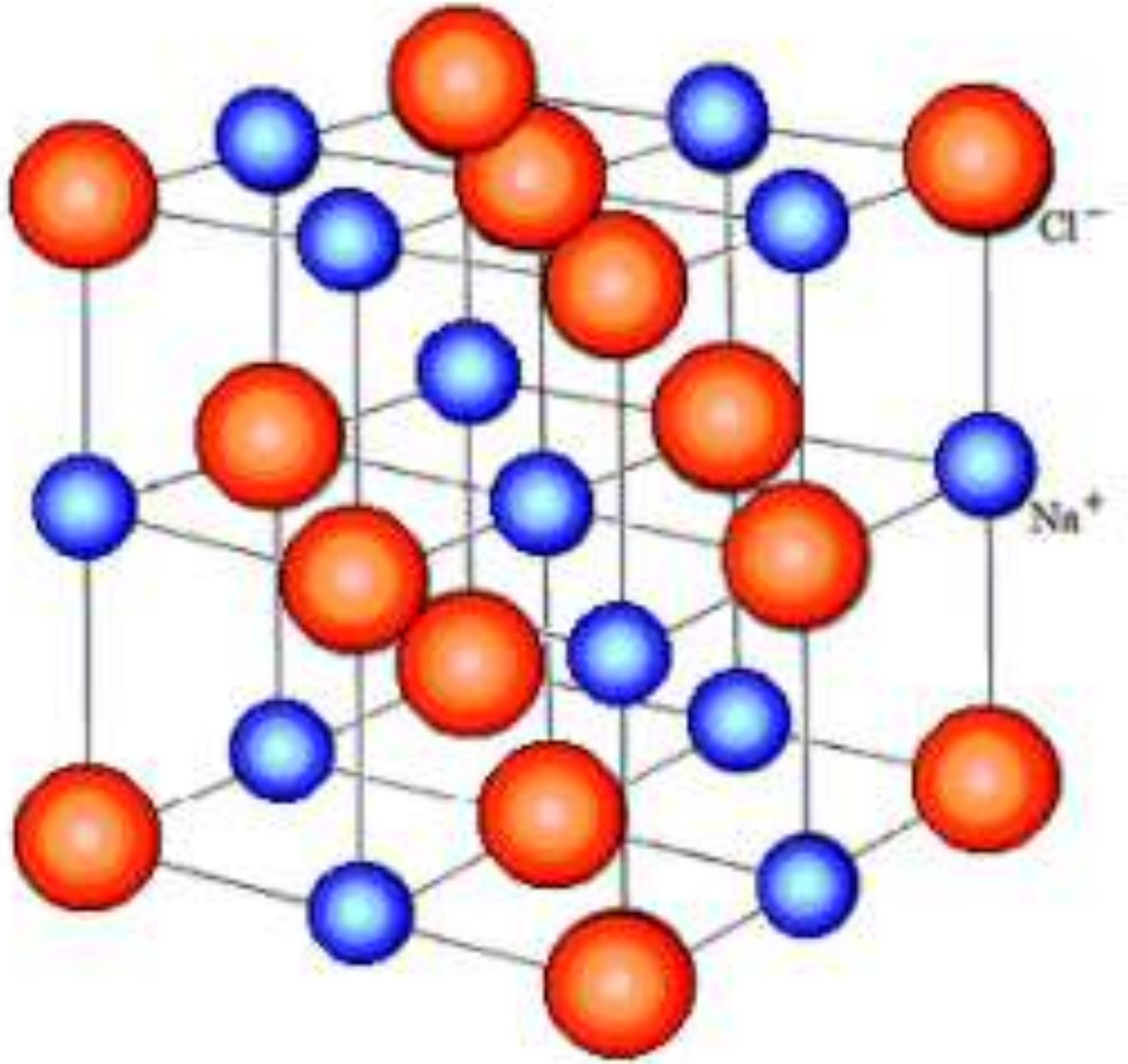


Crystalline solids
Atomic solids
Molecular solids
Ionic solids
Covalent solids
Metallic Solids

Ionic Solids

In ionic solids, the constituent particles are ions of opposite charges. Each ion is surrounded by a definite number of ions of opposite charge.

- The number of ions that surround a particular ion of opposite charge its called co – ordination number of the ion.
- For example, in sodium chloride crystal each sodium ion is surrounded by six chloride ions. Hence coordination number of is 6. At the same time each chloride ion is surrounded by six ions. Therefore the co – ordination number of ion is also 6.


Cl⁻
Na⁺

- However, in calcium fluoride crystal each ion is surrounded by eight fluoride ions and each ion is surrounded by four ions.
- Thus, in crystal co – ordination numbers of and ions are respectively 4 and 8.
- The inter particle forces in ionic solids are ionic bonds operating between the ions of opposite charges some examples of ionic solids are : sodium chloride (NaCl) ; cesium chloride (CsCl), zinc sulphide (ZnS), calcium fluoride, etc.

Characteristics of Ionic Solids

Some common characteristics of ionic solids are as follows:

- They are hard, brittle and have low volatility.
- They have high melting points.
- They are poor conductors of electricity in solid state, however they become good conductors of electricity in molten state or in dissolved state.
- They are generally soluble in polar solvents like water.

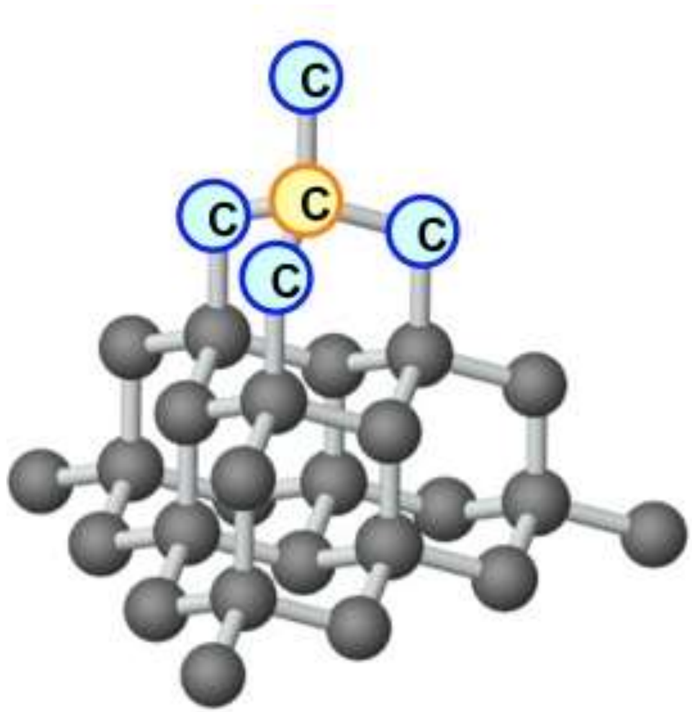
Covalent Solids

In these types of solids the constituent particles are atoms of same or different elements connected to each other by covalent bond network.

- ❖ For example, in diamond only carbon atoms constitute the covalent network while carborundum covalent bond network is constituted by silicon and carbon atoms. Obviously, the interparticle forces operating in these solids are covalent bonds.
- ❖ These solids are also called network solids because the covalent bonds extend in three dimensions forming a giant interlocking structure.

❖ Some examples of covalent solids are :

Diamond, silicon carbide, aluminum nitrite etc.



Characteristics of Covalent Solids

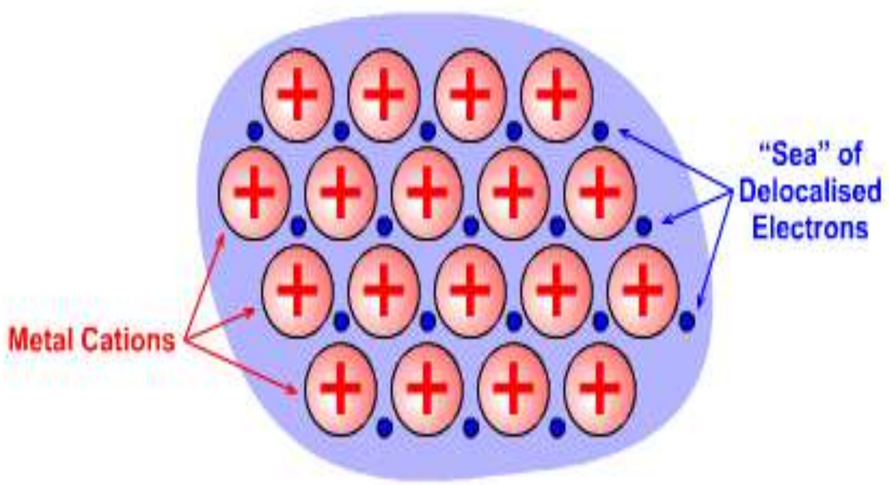
Some common characteristics of covalent solids are :

- They are very hard. Diamond is the hardest naturally occurring substance.
- They have very high melting points.
- They are poor conductors of heat and electricity.
- They have high heats of fusion.

Metallic Solids

In these type of solids, the constituent particles are metal atoms. The interparticle forces in these solids are metallic bonds. In the metallic crystals the metal atoms occupy the fixed positions but their valence electrons are mobile.

The close packed assembly of metal kernels (part of metal atom without valence electrons) remain immersed in the sea of mobile valence electrons. The attractive force between the kernels and mobile valence electrons is termed as metallic bond.



Characteristics of Metallic Solids

The common characteristics of metallic solids are as follows:

❖ They generally range from soft to very hard.

❖ They are malleable and ductile.

❖ They are good conductors of heat and electricity.

❖ They possess bright luster.

❖ They have high melting and boiling points.

❖ They have moderate heats of fusion.

Atomic Solids

In these solids the constituent particles are atoms. These closely packed atoms are held up by London dispersion forces. Some examples are crystals of noble gases. Such solids are very soft, possess very low melting points and poor conductors of heat and electricity.

Molecular Solids

In these solids, the constituent particles which pack up together are molecules of the substance. These molecules may be non – polar (dipole moment = 0) such as etc. or they may be polar (dipole moment > 0) like etc.

Molecular solids

Non-polar	Polar	Hydrogen-bonded
Soft	Soft	Hard
Insulator of electricity	Insulator of electricity	Insulator of electricity
Very low melting point	Low melting point	Low melting point
Intermolecular forces - Despersion or London forces	Intermolecular forces - Dipole - dipole interaction	Intermolecular forces - Hydrogen bonding
Example - Ar, CCl_4, H_2, CO_2	Example - HCl, SO_2	Example - H_2O (ice)

1. Non-Polar Molecular Solids

- ✓ These solids are formed from molecules or atoms that share a non-polar covalent bond. The atoms or molecules are held by weak dispersion force or by London forces.
- ✓ The physical nature of non-polar solids are soft.
- ✓ They don't conduct electricity so they are insulators.
- ✓ They have a very low melting point.
- ✓ Examples: H_2, Cl_2, I_2 etc.

2. Polar Molecular Solids

- These solids are held together by polar covalent bonds and the atoms/molecules are bonded by relatively stronger dipole-dipole interactions.
- The physical nature is soft and most of these are gases or liquids at room temperature.
- They do not conduct electricity and they have a higher melting point than the non -polar molecular solids.
- Examples: HCl, SO_2, NH_3 etc.

3. Hydrogen-Bonded Molecular Solids

- The solids contain polar covalent bonds with Hydrogen, Fluorine, Oxygen and Nitrogen atoms. In these solids, molecules are held together via strong hydrogen bonding.
- The physical nature of such solids are hard.
- They do not conduct electricity.
- The physical state of these solids are volatile liquids or soft solids under room temperature.
- They have a low melting point.
- Examples: H_2O (Ice).

Characteristics of Molecular Solids

Some of the general characteristics of molecular solids are :

- They are generally soft.
- Their melting points are low to moderately high.
- The melting points of solids with non – polar molecules are relatively low whereas solids with polar molecules have moderately high melting points.
- They are generally bad conductors of heat and electricity.
- They have generally low density.

EXERCISES

1. What is the difference between a crystalline solid and an amorphous solid?
2. What two properties do solids have in common? What two properties of solids can vary?
3. Explain how the bonding in an ionic solid explains some of the properties of these solids.
4. Explain how the bonding in a molecular solid explains some of the properties of these solids.
5. Explain how the bonding in a covalent network solid explains some of the properties of these solids.
6. Explain how the bonding in a metallic solid explains some of the properties of these solids.
7. Which type(s) of solid has/have high melting points?
8. Which type(s) of solid conduct(s) electricity in their solid state? In their liquid state?
9. Which type of solid(s) is/are considered relatively soft?
10. Which type of solid(s) is/are considered very hard?

11. Predict the type of solid exhibited by each substance.
a. Hg
b. PH_3
c. CaF_2
12. Predict the type of solid exhibited by each substance.
a. $(CH_2)_n$ (polyethylene, a form of plastic)
b. PCl_3
c. NH_4Cl
13. Predict the type of solid exhibited by each substance.
a. SO_3
b.Br_2
c. Na_2SO_3
14. Predict the type of solid exhibited by each substance.
a. BN (boron nitride, a diamond-like compound)
b. B_2O_3
C. $NaBF_4$
15. Predict the type of solid exhibited by each substance.
a. H_2S
b. Si
c. CsF
16. Predict the type of solid exhibited by each substance.
a.Co
b. CO
c. $CaCO_3$

Reference

WEB LINK

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