

SOLID STATE

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Learning outcomes

By the end of this chapter, Students should be able to:

- 7.12 Differentiate between amorphous and crystalline solids.
- 7.13 Describe the properties of crystalline solids (anisotropy, allotropy, somorphism, polymorphism, transition temperature, habit of crystal, crystal growth).
- 7.14 Define unit cell, crystal lattice, efflorescence, deliquescence, hygroscopy, and water of crystallization with examples.

Why do the solids have a fixed shape?

Ans: In solids, the molecules are tightly packed with no or very little intermolecular space, which gives a certain shape, so the solids have a fixed shape.

7.3.1 Types of solids

Solids can be classified based on the dominant type of bonds they involve. Viz

- a. Ionic solids
 - b. Molecular solids
 - c. Covalent solids
 - d. Metallic solids
- (as studied in detail in Chemical bonding and shape of molecules)

1. What are ionic crystals? Give examples.

Ans: A crystal in which ions are arranged in a specific pattern to give a certain structure is called an ionic crystal. E.g. NaCl, KNO₃, KCl, etc.

2. How does a covalent crystal differ from an ionic crystal?

Covalent crystal	Ionic crystal
The crystal in which atoms are held together by covalent bonds is called a covalent crystal, e.g., diamond, graphite, silica, etc.	A crystal in which ions are arranged in a specific pattern to give a certain structure is called an ionic crystal. E.g., NaCl, KNO ₃ , KCl, etc.

3. What are molecular crystals? Give examples.

Ans: The crystal in which the molecules are constituent particles and are held together by the weak Van der Waals force is a molecular crystal. E.g., phosphorus, iodine, etc.

4. Metallic crystals are good conductors of heat and electricity. Justify the statement.

Ans: The constituents of metallic crystals are metallic ions in the pool of valence electrons where kernels are embedded. Due to the presence of these free electrons, metallic crystals are good conductors of heat and electricity.

5. NaCl is a bad conductor in the solid state but a good conductor in the molten state. Explain.

Ans: In the solid state, Na⁺ and Cl⁻ ions are held strongly by ionic interaction, so they are immobile, but in the molten state, those ions are in a mobile nature. So NaCl is a bad conductor in the solid state but a good conductor in the molten state.

6. Why are the molecular crystals soft and volatile?

Ans: Due to weak Van der Waals interaction among constituent molecules, molecular crystals are volatile and soft in nature.

7.3.2 Amorphous and crystalline solids

Amorphous solid	Crystalline solid
Amorphous solids do not possess a certain geometrical shape and are supercooled liquids.	Crystalline solids possess a certain geometrical shape, and molecules are arranged in a definite pattern within it.
They generally melt at a range of temperatures.	They have sharp melting points.
They do not have sharp edges and plane surfaces.	They have sharp edges and plane surfaces.
They are isotropic.	They are anisotropic.

An isotropic solid is a solid material in which physical properties do not depend on the orientation. E.g. Glass

When the properties of a solid vary with different crystallographic orientations, the material is said to be an anisotropic solid. E.g. NaCl crystal

7.3.3 Efflorescent, Deliquescent, and Hygroscopic Solids

Efflorescence

The spontaneous phenomenon of losing one or more water molecules (water of crystallization) by hydrated crystals when exposed to the atmosphere is called efflorescence, and the substance is said to be efflorescent.

This occurs due to the greater vapour pressure of the substance than the vapour pressure of the atmosphere. E.g., decahydrated sodium carbonate ($\text{Na}_2\text{CO}_3 \cdot 10 \text{H}_2\text{O}$) loses 9 water molecules of water of crystallization on exposure to form monohydrated salt. Other examples are $\text{FeSO}_4 \cdot 7 \text{H}_2\text{O}$, $\text{CuSO}_4 \cdot 7 \text{H}_2\text{O}$ etc.

Hygroscopy

Certain solids absorb water molecules from the air and get hydrated. This is known as hygroscopy. Such solids are called hygroscopic solids. This is due to the lower vapour pressure of such a substance than the vapour pressure of the atmosphere.

For example, anhydrous copper sulphate (II) exposed to air becomes pentahydrated salt.

Deliquescence

Some solids absorb moisture from the atmosphere to an extent that they become wet and even change into their solution in some instances. Such solids are said to be deliquescent solids, and the phenomenon is called deliquescence.

This is also due to the lower vapour pressure of the substance than the vapour pressure of the atmosphere, e.g., anhydrous CaCl_2 , NaOH , KOH , etc.

7.3.4 Crystallization and crystal growth

Crystallization is the slow precipitation (Precipitation is the formation of a solid in a solution during a chemical reaction or by diffusion in a solid) of crystals from a solution of a substance.

Crystallization may be defined as the process of obtaining crystals by cooling the saturated solution of the substance heated upto crystallization point.

The crystallization point is the temperature at which a saturated solution, when heated, is cooled to obtain crystals.

Crystals have their constituent particles arranged regularly in short and long range in fixed spots in the crystal lattice. But the constituent particles of liquid or solutions are irregularly arranged and moving continuously throughout the body of the liquid. The crystallization process involves the arrangement of the particles in a regular pattern from the solution to crystals in a stepwise manner. This process is called crystal growth.

7.3.5 Water of crystallization

Most of the crystals consist of a certain number of water molecules. The number of water molecules associated with one molecule of anhydrous solid to form a hydrated crystal is called the number of water of crystallization.

Crystals having water of crystallization are called hydrated salts, and those without water of crystallization are called anhydrous salts.

Water of crystallization serves as an integral part of the crystal and determines the geometry of the crystals, even other properties in some cases.

E.g.,

Molecular formula	Name	Common name
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	Copper sulphate pentahydrate	Blue vitriol
$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	Zinc sulphate heptahydrate	White vitriol
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	Ferrous sulphate heptahydrate	Green vitriol
$\text{FeSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$	Ferrous ammonium sulphate hexahydrate	Mohr's salt

There can be some crystals without water of crystallization, e.g., NaCl crystals.

7. Write the differences between hydrated and anhydrous crystalline solids.

Ans:

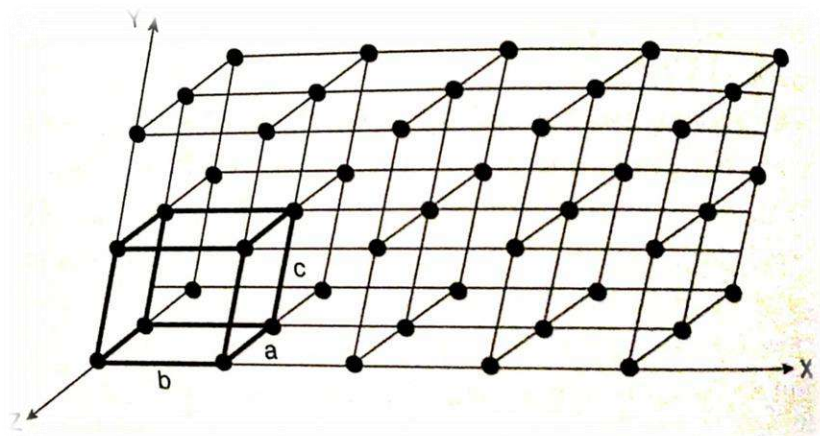
Hydrated crystalline solid	Anhydrous crystalline solid
The crystals that contain a certain number of water molecules as their bonded part are hydrated crystalline solids.	The crystals that do not possess water of crystallization are anhydrous crystalline solids.
For example: pentahydrated copper sulphate; $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	For example: sodium nitrate; NaNO_3

7.3.6 Introduction to crystal lattice and unit cell

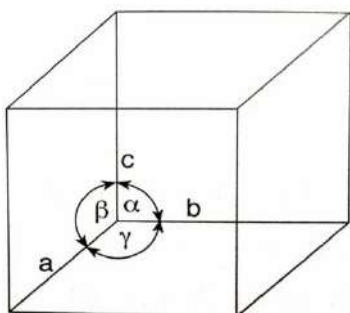
The constituent particles of a crystal are arranged in a regular repeating manner in a 3D space.

The regular arrangement of the constituting units of a crystal in three-dimensional space is called a crystal lattice.

The points occupied by the constituent particles in a crystal are called crystal points or lattice points. The arrangement of these crystal points or lattice points in the crystals is called the crystal lattice.



A three-dimensional smallest group of lattice points is called a unit cell.



Material for further study:

8. Explain the process of determination of water of crystallization.

Ans: The number of water molecules associated with one molecule of solid can be determined by knowing the weight of anhydrous solid and the amount of water associated with it, and that is the water of crystallization. This method of determining water of crystallization is the gravimetric method. In this method, a certain amount of hydrated solid is taken in a clean, dried, preweighed crucible, followed by gradual heating to remove all the water of crystallization from it. The weight of anhydrous solid is determined after cooling the crucible in a dessicator. The process of heating, cooling, and weighing is repeated until a consistent weight of anhydrous solid is obtained. After knowing the weight of anhydrous solid, associated water, and molecular weight of the compound, we can determine the water of crystallization of the crystalline compound.

Let, weight of empty crucible = w_1

Weight of crucible+ hydrated salt = w_2

Weight of crucible +anhydrous solid = w_3

Weight of hydrated solid = $w_2 - w_1$

Weight of anhydrated solid = $w_3 - w_1$

Weight of water = $w_2 - w_3$

Now, $(w_3 - w_1)$ gm of anhydrous solid is associated with $(w_2 - w_3)$ gm of water molecules. Let the molecular weight of the salt be M , then m gm of anhydrous salt is associated with $(w_2 - w_3) * M / (w_3 - w_1)$

So, the number of water associated with one molecule of the salt is = number of water of crystallization = $(w_2 - w_3) * M / (w_3 - w_1)(M)$.

9. How could the crystal of copper sulphate be prepared?

Ans: To prepare a crystal of copper sulphate, here is the method:

Take China dish

Glass rod

Wash bottle

Copper sulphate

Burner

250 ml beaker

Wire gauze

Tripod stand

25 ml water

Then follow the steps as follows:

Method

1. Take a clean beaker (250 ml) and put the powdered impure sample of copper sulphate in it.
2. Add distilled water and stir the contents gently with the help of a glass rod.
3. To make the solution clearer, add two or three drops of concentrated sulphuric acid in it.
4. Heat the solution in the beaker to 60-70°C on a wire gauze.
5. Stir it continuously and add more impure copper sulphate until no more of it dissolves.
6. Filter the solution and collect the filtrate in a china dish.
7. Place the china dish over the wire gauze kept over a tripod stand and heat it gently (do not boil).
8. As the solution gets heated, stir it with a glass rod. This helps in uniform evaporation and prevents the formation of a solid crust.
9. When the volume of the solution is reduced to one-half, take out a drop of the concentrated solution on one end of the glass rod and cool it by blowing air. Formation of a thin crust indicates that the crystallization point has been reached.
10. Turn off the burner, cover the dish with a watch glass, and keep it undisturbed. As the solution cools down, crystals separate. Slow cooling ensures better crystallization.
11. Decant the mother liquor and wash the crystals with a thin stream of cold water with the help of a wash bottle.
12. Dry the crystals by pressing them gently between sheets of filter paper.

After this, we will observe Blue colored crystals of copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) formed.

By this, one can make a crystal of copper sulphate.

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*****This is not a complete note. It is to guide you. It is recommended to study the prescribed textbooks along with this material. *****