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## 8

# COLLOIDS

You are familiar with solutions. They play an important role in our life. A large number of substances such as milk, butter, cheese, cream, coloured gems, boot polish, rubber, ink also play an important role in our daily life. They are mixtures of special type. They are colloidal solutions. The term colloid has been derived from two terms, namely colla and oids. 'Kolla' means glue and 'Oids' means like i.e. glue-like. The size of the particles in colloidal solutions is bigger than the size of particles present in solutions of sugar or salt in water but smaller than the size of particles in suspensions. In this lesson you will learn about the methods of preparation, properties and applications of colloidal solutions.



## OBJECTIVES

After reading this lesson you will be able to:

- explain the difference between true solution, colloidal solution and suspension;
- identify phases of colloidal solution;
- classify colloidal solutions;
- describe methods of preparation of colloids;
- explain some properties of colloidal solutions;
- explain Hardy Schultz Rule;
- recognise the difference between gel and emulsion;
- cite examples of the application of colloids in daily life; and
- define nano materials and list some of their properties.

### 8.1 DISTINCTION BETWEEN A TRUE SOLUTION, COLLOIDAL SOLUTION AND SUSPENSION

You may recall that solution of sugar in water is homogeneous but milk is not. When you closely look at milk you can see oil droplets floating in it. Thus, although it appears to be homogenous it is actually heterogenous in nature. The nature of



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the solution formed depends upon the size of the solute particles. If the size of the solute particles is less than 1 nm it will form **true solution** but when the size is between 1 to 100 nm then it will form colloidal solution. When the size of solute particles is greater than 100 nm it will form a suspension. Therefore we may conclude that colloidal solution is an intermediate state between true solution and suspension (Table 8.1).

**Table 8.1: Some important properties of true solutions, colloids and suspensions**

S.No.	Name of Property	True Solution	Colloids Solution	Suspension
1.	Size	Size of particles is less than 1 nm	Size of particles is between 1nm and 100 nm.	Size of particles is greater than 100 nm.
2.	Filterability	Pass through ordinary filter paper and also through animal membrane.	Pass through ordinary filter paper but not through animal membrane.	Do not pass through filter paper or animal membrane.
3.	Settling	Particles do not settle down on keeping	Particles do not settle down on their own but can be made to settle down by centrifugation.	Particles settle down on their own under gravity.
4.	Visibility	Particles are invisible to the naked eye as well as under a microscope.	Particles are invisible to the naked eye but their scattering effect can be observed with the help of a microscope.	Particles are visible to the naked eye.
5.	Separation	The solute and solvent cannot be separated by ordinary filtration or by ultra filtration.	The solute and solvent cannot be separated by ordinary filtration but can be separated by ultra-filtration.	The solute and solvent can be separated by ordinary filtration.
6.	Diffusion	Diffuse quickly	Diffuse slowly	Do not diffuse

**8.2 PHASES OF COLLOIDS SOLUTION**

Colloids solutions are heterogenous in nature and always consist of at least two phases : the **dispersed phase** and the **dispersion medium**.

- **Dispersed Phase :** It is the substance present in small proportion and consists of particles of colloids size (1 to 100 nm).

- **Dispersion Medium** : It is the medium in which the colloids particles are dispersed. For example, in a colloidal solution of sulphur in water, sulphur particles constitute the 'dispersed phase' and water is the 'dispersion medium'.

Each of the two phases namely, dispersed phase and dispersion medium can be solid, liquid or gas. Thus, different types of colloidal solutions are possible depending upon the physical state of the two phases. Different types of colloidal solutions and their examples are shown in Table 8.2. You should note that gases cannot form a colloidal solution between themselves, because they form homogenous mixtures.

Table 8.2 : Types of Colloidal Solutions

S.No.	Dispersed Phase	Dispersion Medium	Type of Colloidal Solution	Examples
1.	Solid	Solid	Solid sol.	Gemstones,
2.	Solid	Liquid	Sol	Paints, muddy water, gold sol, starch sol, arsenious sulphide sol.
3.	Solid	Gas	Aerosol of solids	Smoke, dust in air
4.	Liquid	Solid	Gel	Jellies, Cheese
5.	Liquid	Liquid	Emulsion	Milk, Cream
6.	Liquid	Gas	Aerosol	Mist, fog, cloud
7.	Gas	Solid	Solid foam	Foam rubber, pumice stone
8.	Gas	Liquid	Foam	Froth, whipped cream

Out of the various types of colloidal solutions listed above, the most common are **sols** (solid in liquid type), **gels** (liquid in solid type) and **emulsions** (liquid in liquid type). If the dispersion medium is water then the 'sol' is called a **hydrosol**; and if the dispersion medium is alcohol then the 'sol' is called an **alcosol**.



### INTEXT QUESTIONS 8.1

1. Classify the following into suspension, colloidal solution and true solution. milk, sugar in water, clay in water, blood, boot polish, sand in water, face cream, jelly, foam.
2. Give one example each of  
(a) Sol (b) Gel (c) Aerosol (d) Emulsion
3. What is the difference between an alcosol and hydrosol?
4. How does colloidal solution differ from true solution.



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### 8.3 CLASSIFICATION OF COLLOIDS

Colloidal solutions can be classified in different ways :

- on the basis of interaction between the phases.
- on the basis of molecular size.

#### 8.3.1 Classification Based Upon Interaction

Depending upon the interaction between dispersed phase and the dispersion medium colloidal solutions have been classified into two categories.

- (a) **Lyophilic colloids** : The word 'Lyophilic' means solvent lover. Lyophilic colloidal solutions are those in which the dispersed phase have a great affinity (or love) for the dispersion medium. Substances like gum, gelatine, starch etc when mixed with suitable dispersion medium, directly pass into colloidal state and form colloidal solution. Therefore, such solutions are easily formed simply by bringing dispersed phase and dispersion medium in direct contact with each other. However, these colloidal solutions have an important property i.e. they are reversible in nature. This means that once lyophilic colloidal solution has been formed then dispersed phase and dispersion medium can be separated easily. Once separated these can again be formed by remixing the two phases. These sols are quite stable.

If water is used as dispersion medium then it is termed as hydrophilic colloid.

- (b) **Lyophobic Colloids** : The word 'Lyophobic' means solvent hating. Lyophobic colloidal solutions are those in which the dispersed phase has no affinity for the dispersion medium. Metals like Au, Ag and their hydroxides or sulphides etc., when simply mixed with dispersion medium do not pass directly into colloidal state. These sols have to be prepared by special methods. These sols can be readily precipitated and once precipitated they have little tendency to go back into the colloidal state. Thus these sols are irreversible in nature. Also they are not very stable and require a stabilizing agent to remain in the colloidal form. In case water is used as dispersion medium it is called as hydrophobic sol.

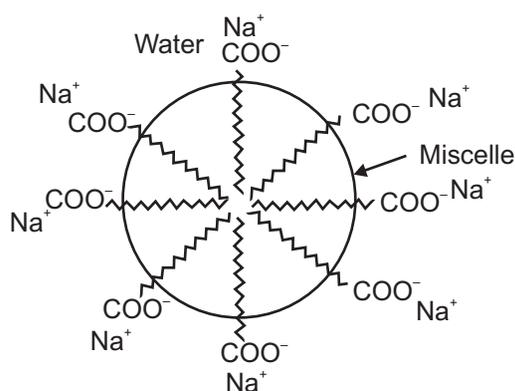
#### 8.3.2 Classification Based on Molecular Size

Depending upon the molecular size the colloids have been classified as

- (a) **Macromolecular colloids** – In this type of colloids the size of the particles of the dispersed phase are big enough to fall in the colloidal dimension as discussed earlier (i.e. 1–100 nm)

Examples of naturally occurring macromolecular colloids are starch, cellulose, proteins etc.

- (b) Multi molecular colloids – Here individually the atoms are not of colloidal size but they aggregate to join together forming a molecule of colloidal dimension. For example sulphur sol contains aggregates of  $S_8$  molecules which fall in colloidal dimension.
- (c) Associated colloids – These are substances which behave as normal electrolyte at low concentration but get associated at higher concentration to form miscelle and behave as colloidal solution. Soap is an example. Soap is sodium salt of long chain fatty acid  $R\text{COONa}$ . When put in water, soap forms  $\text{RCOO}^-$  and  $\text{Na}^+$ . These  $\text{RCOO}^-$  ions associate themselves around dirt particles as shown below forming a miscelle (Fig. 8.1).



**Fig.8.1 :** Aggregation of  $\text{RCOO}^-$  ions to form a micelle.

## 8.4 PREPARATION OF COLLOIDAL SOLUTIONS

As discussed earlier, the lyophilic sols can be prepared directly by mixing the dispersed phase with the dispersion medium. For example, colloidal solutions of starch, gelatin, gum etc. are prepared by simply dissolving these substances in hot water. Similarly, a colloidal sol of cellulose nitrate is obtained by dissolving it in alcohol. The resulting solution is called **collodion**.

However, lyophobic colloids cannot be prepared by **direct method**.

Hence two types of methods are used for preparing lyophobic colloids. These are:

- (i) Physical methods
  - (ii) Chemical methods
- (i) Physical methods**

These methods are employed for obtaining colloidal solutions of metals like gold, silver, platinum etc. (Fig. 8.2)





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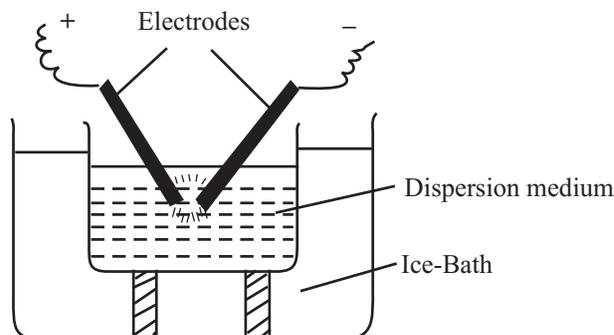


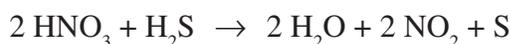
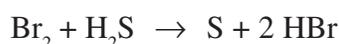
Fig. 8.2 : Preparation of colloidal solution by Bredig's Arc Method

An electric arc is struck between the two metallic electrodes placed in a container of water. The intense heat of the arc converts the metal into vapours, which are condensed immediately in the cold water bath. This results in the formation of particles of colloidal size. We call it as metal sol. e.g. gold sol.

**Peptisation :** Peptisation is the process of converting a freshly prepared precipitate into colloidal form by the addition of a suitable electrolyte. The electrolyte is called peptising agent. For example when ferric chloride is added to a precipitate of ferric hydroxide, ferric hydroxide gets converted into reddish brown coloured colloidal solution. This is due to preferential adsorption of cations of the electrolyte by the precipitate. When  $\text{FeCl}_3$  is added to  $\text{Fe}(\text{OH})_3$ ,  $\text{Fe}^{3+}$  ions from  $\text{FeCl}_3$  are adsorbed by  $\text{Fe}(\text{OH})_3$  particles. Thus the  $\text{Fe}(\text{OH})_3$  particles acquire + ve charge and they start repelling each other forming a colloidal solution.

#### (ii) Chemical Methods : By oxidation

Sulphur sol is obtained by bubbling  $\text{H}_2\text{S}$  gas through the solution of an oxidizing agent like  $\text{HNO}_3$  or  $\text{Br}_2$  water, etc. according to the following equation :



$\text{Fe}(\text{OH})_3$  sol,  $\text{As}_2\text{S}_3$  sol can also be prepared by chemical methods.

### 8.5 PURIFICATION OF COLLOIDAL SOLUTION

When a colloidal solution is prepared it contains certain impurities. These impurities are mainly electrolytic in nature and they tend to destabilise the colloidal solutions. Therefore colloidal solutions are purified by the following methods:

(i) Dialysis

(ii) Electrodialysis

**Dialysis :** The process of dialysis is based on the fact that colloidal particles cannot pass through parchment or cellophane membrane while the ions of the

electrolyte can. The colloidal solution is taken in a bag of cellophane which is suspended in a tub full of fresh water. The impurities diffuse out leaving pure colloidal solution in the bag (Fig. 8.3). This process of separating the particles of colloids from impurities by means of diffusion through a suitable membrane is called *dialysis*.

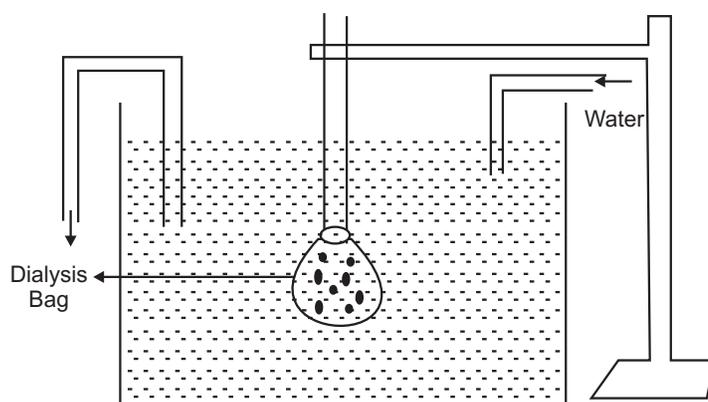


Fig. 8.3 : A dialyser

**Electrodialysis :** The dialysis process is slow and to speed up its rate, it is carried out in the presence of an electrical field. When the electric field is applied through the electrodes, the ions of the electrolyte present as impurity diffuse towards oppositely charged electrodes at a fast rate. The dialysis carried out in the presence of electric field is known as electro dialysis (Fig. 8.4).

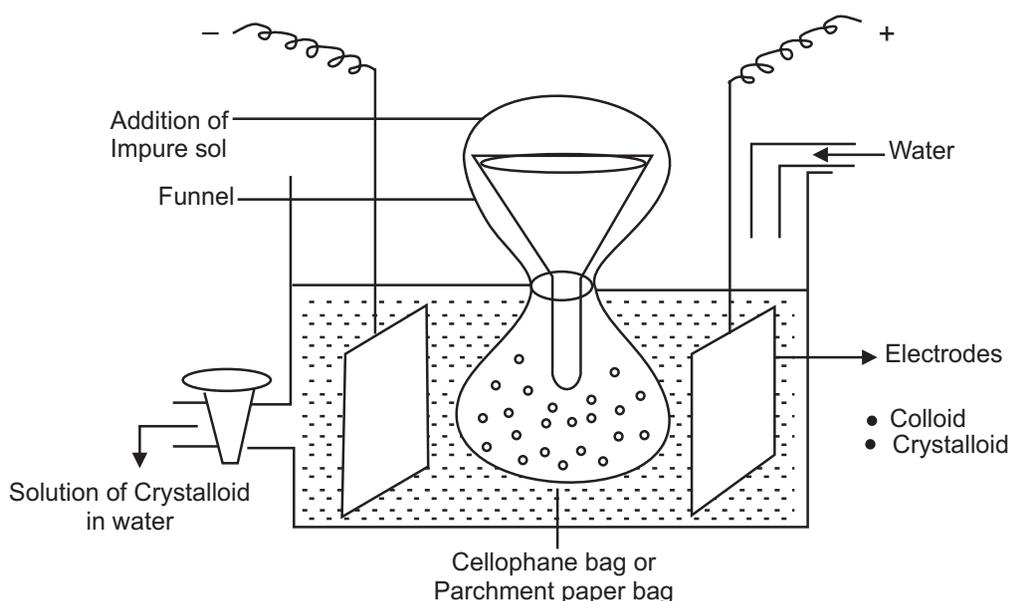


Fig. 8.4 : Electro dialysis



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The most important use of dialysis is the purification of blood in the artificial kidney machine. The dialysis membrane allows the small particles (ions etc.) to pass through, whereas large size particles like haemoglobin do not pass through the membrane.



### INTEXT QUESTIONS 8.2

1. Name two colloids that can be prepared by Bredig's Arc method.
2. Name two colloids that can be prepared by chemical methods.
3. Differentiate between (a) Lyophilic and Lyophobic sol. (b) macromolecular and multimolecular colloids.
4. Explain the formation of miscelle.

### 8.6 PROPERTIES OF COLLOIDS

The properties of colloids are discussed below :

- Heterogeneous character :** Colloidal particles remain within their own boundary surfaces which separates them from the dispersion medium. So a colloidal system is a heterogeneous mixture of two phases. The two phases are dispersed phase and dispersion medium.
- Brownian movement :** It is also termed as Brownian motion and is named after its discoverer Robert Brown (a Botanist.)

Brownian Motion is the zig-zag movement of colloidal particles in continuous and random manner (Fig. 8.5). Brownian motion arises because of the impact of the molecules of the dispersion medium on the particles of dispersed phase. The forces are unequal in different directions. Hence it causes the particles to move in a zig-zag way.

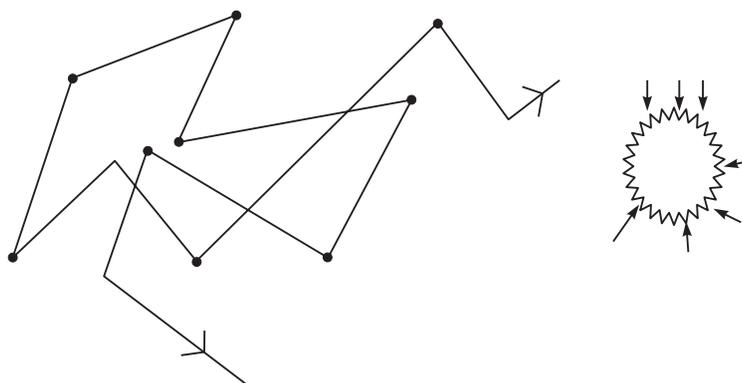


Fig. 8.5 : Brownian Movement

- c) **Tyndall Effect** : Tyndall in 1869, observed that if a strong beam of light is passed through a colloidal solution then the path of light is illuminated. This phenomenon is called Tyndall Effect. This phenomenon is due to scattering of light by colloidal particles (fig.8.6). The same effect is noticed when a beam of light enters a dark room through a slit and becomes visible. This happens due to the scattering of light by particles of dust in the air.

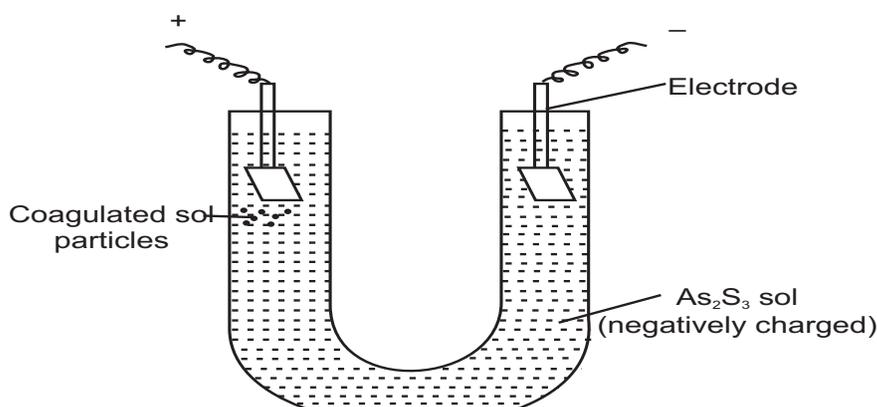


Fig. 8.6 : The Tyndall Effect

- d) **Electrical Properties** : The colloidal particles are electrically charged and carry the same type of charge, either negative or positive. The dispersion medium has an equal and opposite charge. The colloidal particles therefore repel each other and do not cluster together to settle down. For example, arsenious sulphide sol, gold sol, silver sol, etc. contain negatively charged colloidal particles whereas ferric hydroxide, aluminium hydroxide etc. contain positively charged colloidal particles. Origin of charge on colloidal particles is due to:

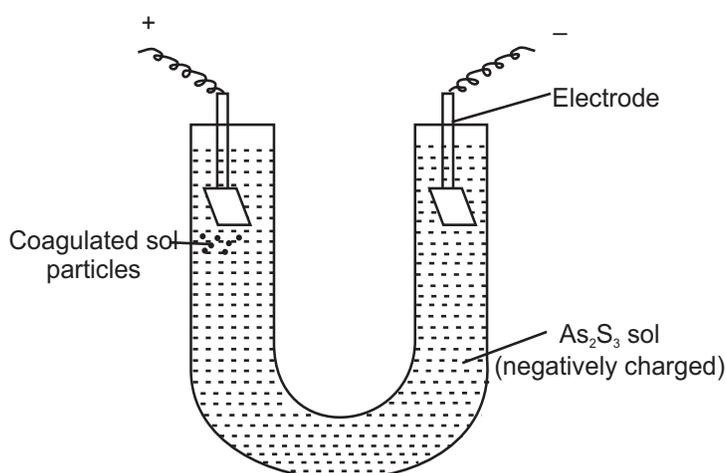


Fig. 8.7 : A set up for Electrophoresis



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## Notes

- (a) Preferential adsorption of cations or anions by colloidal particles.
- (b) Miscelles carry a charge on them due to dissociation.
- (c) During the formation of colloids especially by Bredig arc method, colloidal particles capture electrons and get charged. The existence of charge on a colloidal particle is shown by a process called **electrophoresis**.

**Electrophoresis** is a process which involves the movement of colloidal particles either towards cathode or anode under the influence of electrical field. The apparatus used is as shown in Fig 8.7.

### 8.7 COAGULATION OR PRECIPITATION

The stability of the lyophobic sols is due to the presence of charge on colloidal particles. If, somehow, the charge is removed, the particles will come nearer to each other to form aggregates (or coagulate) and settle down under the force of gravity.

**The process of settling of colloidal particles is called coagulation or precipitation of the sol.**

The coagulation of the lyophobic sols can be carried out in the following ways:

- (i) *By electrophoresis*: The colloidal particles move towards oppositely charged electrodes, get discharged and precipitated.
- (ii) *By mixing two oppositely charged sols*: Oppositely charged sols when mixed in almost equal proportions, neutralise their charges and get partially or completely precipitated. Mixing of hydrated ferric oxide (+ve sol) and arsenious sulphide (-ve sol) bring them in the precipitated forms. This type of coagulation is called mutual coagulation.
- (iii) *By boiling*: When a sol is boiled, the adsorbed layer is disturbed due to increased collisions with the molecules of dispersion medium. This reduces the charge on the particles and ultimately lead to settling down in the form of a precipitate.
- (iv) *By addition of electrolytes*: When excess of an electrolyte is added, the colloidal particles are precipitated. The reason is that colloids interact with ions carrying charge opposite to that present on themselves. This causes neutralisation leading to their coagulation.

The ion responsible for neutralisation of charge on the particles is called the coagulating ion. A negative ion causes the precipitation of positively charged sol and vice versa.

It has been observed that, generally, the greater the valence of the flocculating ion added, the greater is its power to cause precipitation.

This is known as **Hardy-Schulze rule**. In the coagulation of a negative sol, the flocculating power is in the order:



Similarly, in the coagulation of a positive sol, the flocculating power is in the order:



The minimum concentration of an electrolyte in millimoles per litre required to cause precipitation of a sol in two hours is called coagulating value. The smaller the quantity needed, the higher will be the coagulating power of an ion.

### 8.7.1 Coagulation of lyophilic sols

There are mainly two factors which are responsible for the stability of lyophilic sols. These factors are the charge and solvation of the colloidal particles. When these two factors are removed, a lyophilic sol can be coagulated. This is done (i) by adding an electrolyte and (ii) by adding a suitable solvent. When solvents such as alcohol and acetone are added to hydrophilic sols, the dehydration of dispersed phase occurs. Under this condition, a small quantity of electrolyte can bring about coagulation.

### Protection of colloids

Lyophilic sols are more stable than lyophobic sols. This is due to the fact that lyophilic colloids are extensively solvated, i.e., colloidal particles are covered by a sheath of the liquid in which they are dispersed.

Lyophilic colloids have a unique property of protecting lyophobic colloids. When a lyophilic sol is added to the lyophobic sol, the lyophilic particles form a layer around lyophobic particles and thus protect the latter from electrolytes. Lyophilic colloids used for this purpose are called protective colloids.

## 8.8 APPLICATIONS OF COLLOIDAL SOLUTIONS

Colloids play a very important role in our daily life. Some of these applications are discussed below:

- (i) **Sewage disposal** : Colloidal particles of dirt, etc. carry electric charge. When sewage is allowed to pass through metallic plates kept at a high potential,



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the colloidal particles move to the oppositely charged electrode and get precipitated there. Hence sewage water is purified.

- (ii) **Purification of Water in Wells :** When alum is added to muddy water, the negatively charged particles of the colloid are neutralized by  $Al^{3+}$  ions. Hence the mud particles settle down and the water can be filtered and used.

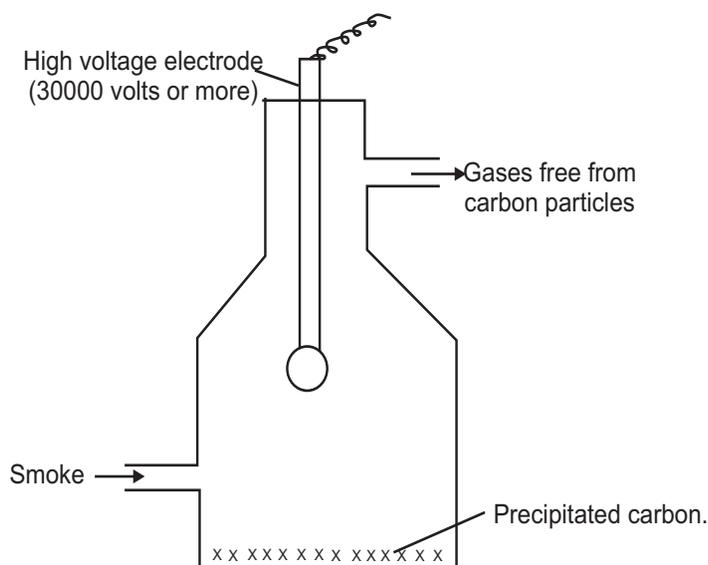


Fig.8.8 : Cottrell smoke precipitator

- (iii) **Smoke Precipitation :** Smoke particles are actually electrically charged colloidal particles of carbon in air. Precipitation of this carbon is done in a **Cottrell's Precipitator**. Smoke from chimneys is allowed to pass through a chamber having a number of metallic plates connected to a source of high potential as shown in Fig. 8.8. Charged particles of smoke get attracted to the oppositely charged electrode and get precipitated and hot purified air passes out.

Other applications in day to day life are :

- (i) **Photography :** A colloidal solution of silver bromide in gelatin is applied on glass plates or celluloid films to form photo-sensitive plates in photography.
- (ii) **Clotting of Blood :** Blood is a colloidal solution and is negatively charged. On applying a solution of  $FeCl_3$  bleeding stops and clotting of the colloidal particles of blood takes place.
- (iii) **Rubber Plating :** Latex is a colloidal solution of negatively charged rubber particles. The object to be rubber plated is made the anode in the rubber plating bath. The negatively charged rubber particles move towards the anode and get deposited on it.

(iv) **Blue Colour of Sky** : Have you ever wondered why is the sky blue? It is because the colloidal dust particles floating about in the sky scatter blue light, that makes the sky appear blue. In the absence of these colloidal particles the sky would have appeared dark throughout.

## 8.8 EMULSION AND GEL

Emulsions are colloidal solutions in which both the dispersed phase and dispersion medium are liquids. However, the two liquids are immiscible, as miscible liquids will form true solution.

Emulsion are of two kinds :

- (a) **Oil-in-water emulsion** : Here the dispersed phase is oil while the dispersion medium is water. Milk is an example of this kind as in milk liquid fats are dispersed in water. Vanishing cream is another example.
- (b) **Water-in-oil emulsion** : Here dispersed phase is water and dispersion medium is oil. Butter, cod- liver oil, cold creams are examples of this type.

The liquids forming emulsion i.e. oil and water will separate out on keeping as they are immiscible. Therefore an emulsifying agent or emulsifier is added to stabilise the emulsion. Soap is a common **emulsifier**. The preparation of emulsion in the presence of an emulsifier is called emulsification.

How does an emulsifier work? It is believed that an emulsifier gets concentrated at the interface between oil and water i.e. the surface at which oil and water come in contact with each other. It acts as a binder between oil and water.

**Applications of Emulsions** - Emulsions play very important role in our daily life. Some of the common applications are given below :

1. The cleansing action of soap and synthetic detergents for washing clothes, bathing etc is based upon the formation of oil in water type emulsion.
2. Milk is an emulsion of fat in water. Milk cream and butter are also emulsions.
3. Various cold creams, vanishing creams, body lotions etc. are all emulsions.
4. Various oily drugs such as cod liver oil are administered in the form of emulsion for their better and faster absorption. Some ointments are also in the form of emulsions.
5. The digestion of fats in the intestine occurs by the process of emulsification.
6. Emulsions are used for concentrating the sulphide ores by froth flotation process. Finely powdered ore is treated with an oil emulsion and the mixture is vigorously agitated by compressed air when the ore particles are carried to the surface and removed.





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**Gels** - Gels are the type of colloids in which the dispersed phase is a liquid and the dispersion medium is a solid. Cheese, jelly, boot polish are common examples of gel. Most of the commonly used gels are hydrophilic colloidal solution in which a dilute solution, under suitable conditions set as elastic semi solid masses. For example 5% aqueous solution of gelatin in water on cooling forms the jelly block.

Gels may shrink on keeping by losing some of the liquid held by them. This is known as **syneresis** or resetting on standing.

Gels are divided in two categories elastic gels and non elastic gels. Elastic gels are reversible. When partly dehydrated on losing water, they change back into the original form on addition of water. The non elastic gels are not reversible.

Gels are useful in many ways. Silica, cheese, jelly, boot polish, curd are commonly used gels. Solidified alcohol fuel is a gel of alcohol in calcium acetate.

In recent past nano materials have attracted enormous interest because of their potential for wide ranging applications in number of fields like medicine, electronics and various industries. They can be metals, ceramics, polymeric materials or composite materials.

A material containing particles with dimension in the size range 1 nm – 100 nm in atleast one direction is termed as **nano material**. One nanometre is  $10^{-9}$ m which is extremely small in size. It is about the size of three to five atoms lined up in a row.

Nano materials have been produced and in use for hundreds of years. The beautiful ruby red colour of some types of glass is due to the presence of nano particles of gold in it. The decorative lustre found on some articles of medieval pottery is due to nano particles of some metals in the glaze.

Nano materials fall in two categories (i)fullerenes and (ii) inorganic nano materials.

**(i) Fullerenes**

Fullerenes are allotropes of carbon which are hollow carbon spheres consisting of large number of carbon atoms bonded chemically like  $C_{60}$ .

**(ii) Inorganic nano particles**

Inorganic nano particles are made of metals, semiconductors or oxides with peculiar electrical, mechanical, optical or chemical properties.

**Properties**

Nanomaterials are available in great variety and the range of their properties and possible applications is enormous.

- (i) They are used for making miniature batteries, super absorbents, extremely tiny electronic devices, parts of automobiles and as packaging films.
- (ii) Nanocapsules and nanodevices present new possibilities for drug delivery, gene therapy, and medical diagnostics.
- (iii) Nanocomposites are obtained by mixing a small quantity of nano material to polymers. For example, adding such small amounts as 2% by volume of silicate nanoparticles to a polyimide resin increases the latter's strength by 100%. Addition of nanoparticles not only improves the mechanical properties, but has also been shown to improve thermal stability.
- (iv) Nano materials generally have high plasticity.
- (v) Due to their large surface, nanoparticles made of transition element oxides exhibit catalytic properties
- (vi) Magnetic nanoparticles show super paramagnetism and have lead to the discovery of a new class of permanent magnetic materials.

**WHAT YOU HAVE LEARNT**

- Size of the particles in the colloidal state is intermediate between that of suspension and true solution.
- There are eight different types of colloidal systems.
- Sols are classified on the basis of (a) interaction between dispersed phase and dispersion medium (b) molecular size of dispersed phase.
- Colloidal solutions are prepared by physical and chemical methods.
- The zig zag motion of colloidal particles is called Brownian motion.
- Colloidal size particles scatter light and so the path of light becomes visible in a semi darkened room due to dust particles.
- Colloidal particles may carry electric charge.
- A colloidal dispersion of a liquid in another liquid is called an emulsion.
- A colloidal solution of a liquid dispersed in a solid medium is called a gel.
- Colloids are extremely useful to mankind both in daily life and in industry.
- Nano materials contain particles with dimension of 1–100 nm in at least in one direction. They have special properties and find many applications.



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**TERMINAL EXERCISE**

- List three differences between a true solution and a colloidal solution.
- Describe one method of preparation of
  - a lyophilic colloid
  - a lyophobic colloid
- What are associated colloids?
- What is Brownian motion? How does it originate?
- Why bleeding from a fresh cut stops on applying alum?
- Two beakers A and B contain ferric hydroxide sol and NaCl solution respectively. When a beam of light is allowed to converge on them, (in a darkened room), beam of light is visible in beaker A but not in beaker B. Give the reason. What is this effect called?
- Define the following terms and give two examples of each
  - Gel
  - Sol
- Describe two important applications of colloidal solutions.
- Give two examples of emulsions used in daily life.
- Explain the role of emulsifier in an emulsion?
- What are nano materials? Give their three applications.

**ANSWERS TO THE INTEXT QUESTIONS****8.1**

- |               |  |
|---------------|--|
| Suspension    | – Clay in water, Sand in water                       |
| Colloidal     | – Milk, Blood, Boot polish, Face Cream, Jelly, Foam. |
| True Solution | – Sugar in water                                     |
- |          |                   |
|----------|-------------------|
| Sol      | – Starch in water |
| Gel      | – Silica gel      |
| Aerosol  | – Fog             |
| Emulsion | – Milk            |
- |          |  |
|----------|--|
| Alcosol  | – When alcohol is the dispersion medium. |
| Hydrosol | – When water is the dispersion medium.   |

- |   |   |
|---|---|
| <p>4. True solution</p> <ol style="list-style-type: none"> <li>1. Size of solute is less than 1 nm.</li> <li>2. Form transparent solution and allows light to pass through them.</li> </ol> | <p>Colloidal solution</p> <ol style="list-style-type: none"> <li>1. Particle size (1–100) nm.</li> <li>2. Path of light becomes visible.</li> </ol> |
|---|---|

## 8.2

1. Gold sol, Platinum sol
2.  $\text{As}_2\text{S}_3$ ,  $\text{Fe}(\text{OH})_3$  (Arsenious sulphide sol, ferric hydroxide sol)
3. (a) **Lyophilic sol** :
  1. easy to prepare
  2. affinity between dispersed phase and dispersion medium.
  3. Reversible

### Lyophobic

1. special method used for preparation
  2. No affinity between the two phases.
  3. Not reversible
- (b) **Macromolecular** – The size of the colloidal particles large enough to fall in the colloidal dimensions.

**Multimolecular** – Individually the particles are not of colloidal dimensions but they aggregate to join together to form molecules of colloidal size.

4. Refer to section 8.3.2 (c)



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## ADSORPTION AND CATALYSIS

Surface of solids plays a crucial role in many physical and chemical phenomena. There are two main reasons for this special role. Firstly, the surface of a substance interacts first with its surroundings. Secondly, the surface molecules are in a different state as compared to the molecules in the interior of the solid. The surface molecules interact more readily with other substances which come close by and are responsible for many special properties. In this lesson we shall study about two such properties – adsorption and catalysis.



### OBJECTIVES

After reading this lesson you will be able to :

- define adsorption;
- distinguish between physical adsorption and chemisorption;
- list and explain the various factors that affect adsorption;
- state Freundlich adsorption isotherm mathematically and explain it;
- explain Langmuir isotherm;
- define catalysis;
- distinguish between homogeneous and heterogeneous catalysis, and
- explain the role of activation energy in catalysis.

### 15.1 ADSORPTION

The surface of a solid attracts and retains molecules of a gas or a dissolved substance which comes in its contact. These molecules remain only at the surface and do not go deeper into the bulk Fig. 15.2(a).



Notes

The phenomenon of attracting and retaining the molecules of a gas or a dissolved substance by the surface of a solid, resulting in their higher concentration on the surface is called adsorption.

The substance which gets adsorbed is called the **adsorbate** and the solid substance which adsorbs is called the **adsorbent**.

A molecule in the interior of a solid is surrounded by other molecules in all directions (Fig. 15.1). However, a molecule at the surface is surrounded by other molecules within the solid phase but not from the outside. Therefore, these surface molecules have some unbalanced or residual forces.

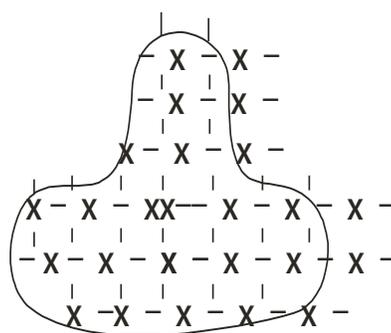


Fig. 15.1 : Molecules in the interior and at the surface of a solid

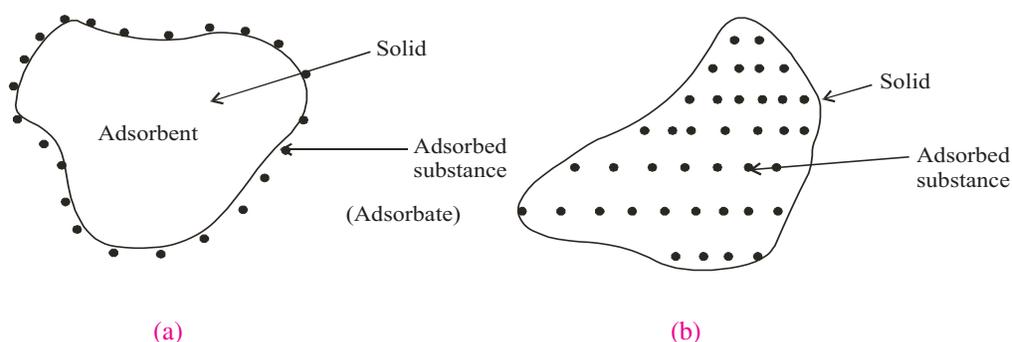


Fig. 15.2 : (a) Adsorption (b) Absorption

### 15.1.1 Adsorption and Absorption

The phenomenon of *adsorption* is different from that of *absorption*. The latter term implies that a substance is uniformly distributed throughout the body of a solid, Fig. 15.2(b). If we leave a small lump of calcium chloride in open, it absorbs water vapour (moisture) from air and after some time even starts dissolving in it. On the other hand if we keep a sample of silica gel in open, it adsorbs water vapour on its surface as shown in Fig. 15.2 (a).

### 15.1.2 Factors Affecting Adsorption

Adsorption occurs on the surface of almost all solids. However, the extent of adsorption of a gas on the surface of a solid depends upon the following factors:

- (i) Nature and surface area of the adsorbent
- (ii) Nature of the adsorbed gas
- (iii) Temperature
- (iv) Pressure of the gas

Let us now discuss these factors briefly.

#### (i) Nature and Surface Area of the Adsorbent

Different solids would adsorb different amounts of the same gas even under similar conditions. Substances like charcoal and silica gel are excellent adsorbents. The substances that are porous in nature and have rough surfaces are better adsorbents.

The extent of adsorption also depends upon the surface area of the solid. Greater the surface area, more is the surface available for adsorption and greater is the adsorption. The surface area depends upon the particle size of the substance. A cube of each side equal to 1 cm has six faces. Each of them is a square with surface area of  $1\text{ cm}^2$ . Thus, the total surface area of this cube is  $6\text{ cm}^2$  Fig. 15.3 (a). If its each side is divided into two equal halves,  $\frac{1}{2}\text{ cm}$  long, and the cube is divided into two equal halves,  $\frac{1}{2}\text{ cm}$  long, and the cube is cut along the lines indicated in the Fig (b), the cube would be divided into 8 smaller cubes with each side  $0.5\text{ cm}$  long [Fig. 15.3 (b)]. Surface area of each small cube would be  $(6 \times 0.5 \times 0.5) = 1.5\text{ cm}^2$  and the total surface area of all the 8 smaller cubes would be  $12\text{ cm}^2$  which is double the surface area of the original cube. If it is subdivided into smaller cubes, each of side equal to  $1 \times 10^{-6}\text{ cm}$  the surface area will increase to  $6 \times 10^6\text{ cm}^2$  or  $600\text{ m}^2$ . The increase in surface area would result in greater adsorption.

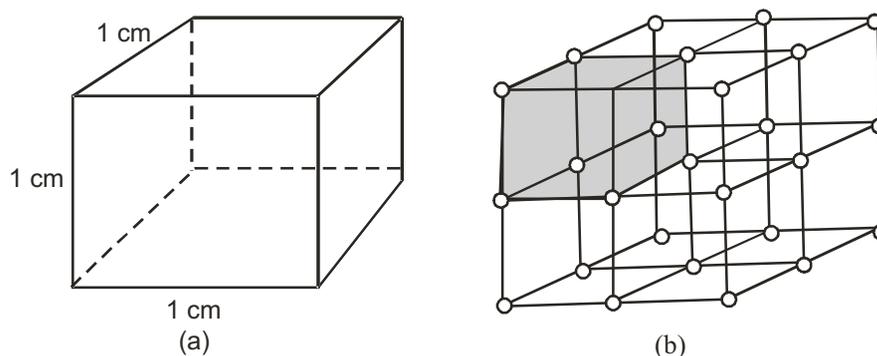


Fig. 15.3 : Subdivision of a cube



Notes



## Notes

Now we can explain why the solids that are porous in nature and have rough surfaces are better adsorbents. It is so because each of these features increases the surface area.

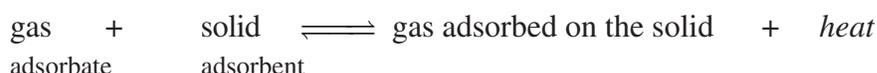
**(ii) The Nature of the Adsorbed Gas**

The extent of adsorption also depends upon the nature of the gas. The gases which are more easily liquifiable or are more soluble in water are more readily adsorbed than others. For example, under similar conditions, the amount of SO<sub>2</sub> or NH<sub>3</sub> adsorbed by charcoal is much more than that of H<sub>2</sub> or O<sub>2</sub> gases. It is because the intermolecular forces are stronger in more easily liquifiable gases, therefore, they get adsorbed more strongly.

**(iii) Temperature**

The extent of adsorption decreases with rise in temperature. For example, under one atmosphere pressure, one gram of charcoal adsorbs about 10 cm<sup>3</sup> of N<sub>2</sub> gas at 272 K, 20 cm<sup>3</sup> at 248 K and 45 cm<sup>3</sup> at 195 K.

*Adsorption is an exothermic process. The change in enthalpy when one mole of a substance is adsorbed, is called **enthalpy of adsorption**. The adsorption process is similar to the condensation process. The reverse process is called **desorption** and is *endothermic* in nature. It is similar to the evaporation process. When a gas is kept in contact with a solid adsorbent in a closed container, a dynamic equilibrium is established in due course of time.*



Since the forward process (adsorption) is exothermic in nature, according to the Le Chatelier's principle, it would be favoured at low temperature. Therefore, the extent of adsorption would increase on decreasing the temperature and would decrease on increasing the temperature.

**(iv) Pressure of the gas**

At a constant temperature the extent of adsorption increases with increase in the pressure of the gas (adsorbate). We shall study the relation between the two in detail a little later.

**15.1.3 Physical and Chemical Adsorption**

Adsorption can be divided into two main categories – physical and chemical adsorption.

*(i) Physical Adsorption*

It is the common type of adsorption. The basic feature of **physical adsorption** is that the adsorbate molecules are held at the surface of the adsorbent by weak van

der Waals forces. These are the forces that exist between particles of all matter. Because of their universal nature, these forces would operate between any adsorbent and adsorbate pair. Therefore, the physical adsorption is observed on surface of any solid. Only, the extent of adsorption varies according to the nature of the adsorbent and adsorbate as discussed earlier.

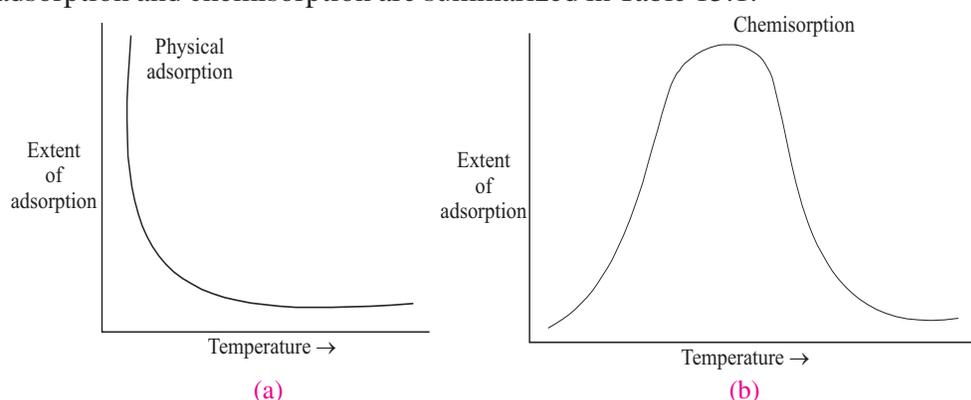
Physical adsorption is characterized by low *enthalpy of adsorption*, that is about  $10 - 40 \text{ kJ mol}^{-1}$ .

Another feature of the physical adsorption of a gas by a solid is that it is *reversible* in nature and an equilibrium is established between the adsorbent and the adsorbate as discussed earlier. Increase of pressure increases the adsorption and the release of pressure desorbs the gas. When temperature is increased, the physical adsorption decreases and when it is lowered, the adsorption increases. In physical adsorption, several layers of adsorbate are adsorbed one over the other.

### (ii) Chemisorption or Chemical Adsorption

We have seen earlier that some unsaturated valencies exist on the surface of a solid. Whenever a chemical combination takes place between the adsorbent and the adsorbate the adsorption becomes very strong. This type of adsorption caused by forces similar to chemical bonds between the adsorbent and the adsorbate is called **chemisorption** or **chemical adsorption**.

The enthalpy of chemisorption is as high as that of chemical bonds (bond enthalpies) and is in the range of  $40 - 400 \text{ kJ mol}^{-1}$ . Chemisorption is highly specific and is possible between a specific adsorbent – adsorbate pair. Like most of the chemical changes it is irreversible. Attempts to release the adsorbed gas gives the gas and some amount of a definite compound. For example, oxygen gas is chemisorbed on tungsten. It is released from the surface of tungsten as a mixture of oxygen and tungsten oxide. Unlike physical adsorption, chemisorption first increases and then decreases with rise in temperature [Fig. 15.4 (b)]. This shows that chemisorption has an energy of activation\*. During chemisorption, only one layer of adsorbate molecules is adsorbed. The main distinctions between physical adsorption and chemisorption are summarized in Table 15.1.



**Fig. 15.4 :** Effect of temperature on (a) physical adsorption and (b) chemisorption.

\* You will learn more about energy of activation later in this lesson.



Notes



Notes

Table 15.1 : Physical Adsorption and Chemisorption

Physical Adsorption	Chemisorption
1. The forces operating between adsorbate and adsorbent are the weak van der Waals forces.	1. The forces operating between adsorbate and adsorbent are strong and similar to chemical bonds.
2. The enthalpy of adsorption is low and ranges from 10 to 40 kJ mol <sup>-1</sup> .	2. The enthalpy of adsorption is high and ranges from 40 to 400 kJ mol <sup>-1</sup> .
3. No activation energy is involved.	3. Significant activation energy is involved.
4. Adsorption occurs more readily at low temperature and high pressure.	4. Chemisorption occurs at relatively high temperature and high pressure.
5. It is not specific in nature. All gases are adsorbed on all solids and no compounds are formed.	5. It is highly specific in nature and occurs between those adsorbents and adsorbates which have a possibility of compound formation between them.
6. It is reversible in nature. The gas is desorbed on increasing the temperature or decreasing the pressure.	6. It is irreversible in nature. Desorption also separates some amount of the compound formed.
7. Multilayer formation is common.	7. Monolayer formation occurs.

15.1.4 Adsorption Isotherms

The extent of adsorption is measured in terms of the quantity  $\frac{x}{m}$  where,  $x$  is the mass of the gas (adsorbate) adsorbed at equilibrium on mass  $m$  of the adsorbent.  $\frac{x}{m}$  is the mass of the adsorbate adsorbed per unit mass of the adsorbent. The graph showing variation in  $\frac{x}{m}$  with pressure( $p$ ) at a constant temperature is called **adsorption isotherm**. Let us see the variation in extent of adsorption in case of gases and of solutes from their solutions.

(i) Adsorption of Gases

The adsorption isotherm of a gas which is adsorbed on a solid is shown in Fig. 15.5. It shows that the extent of adsorption of a gas on a solid increases with the increase in the pressure of the gas,  $p$  at three different constant temperatures. The curves also show that the extent of adsorption, decreases at a fixed pressure as the temperature is increased (see the dotted line).

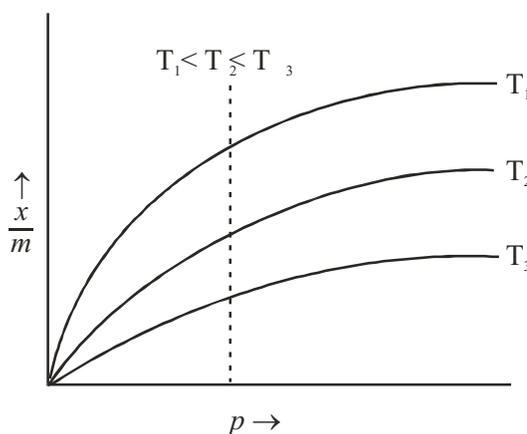


Fig. 17.5 : Adsorption isotherm of a gas

**Freundlich Adsorption Isotherm**

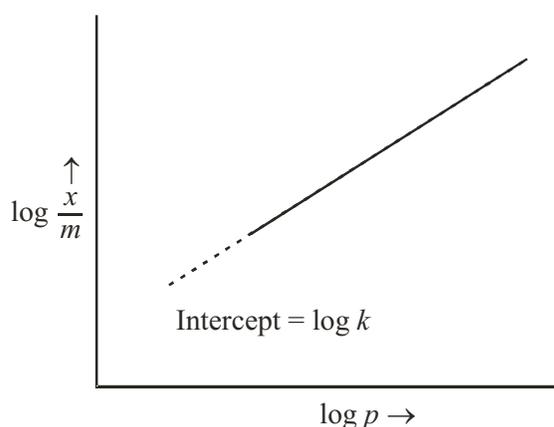
Freundlich gave an empirical mathematical relationship between the extent of adsorption  $\left(\frac{x}{m}\right)$  and the equilibrium pressure ( $p$ ) of the gas as :

$$\frac{x}{m} = k p^{\frac{1}{n}} \quad \text{where } n > 1$$

In this relation  $k$  is a constant at a given temperature and depends upon the nature of the adsorbate and adsorbent. The value of  $n$  changes with pressure. It is 1 at low pressures and increases with pressure. The relationship is valid at a constant temperature. Therefore, it is called **Freundlich Adsorption Isotherm**. On taking logarithm of the above equation, we get

$$\log \frac{x}{m} = \log k + \frac{1}{n} \log p$$

This is an equation of a straight line and a plot of  $\log \frac{x}{m}$  against  $\log p$  should be a straight line with slope  $\frac{1}{n}$  as depicted in Fig. 15.6. In actual practice, a straight line is obtained provided the data at very low and very high pressures is neglected.



*Fig. 15.6 : Plot of  $\log \frac{x}{m}$  against  $\log p$ .*

**15.1.5 Langmuir Adsorption Isotherm**

**Adsorption Isotherm :** One of the drawbacks of the Freundlich adsorption isotherm is that it fails at high pressure of the gas. Langmuir derived an adsorption isotherm on theoretical considerations based on kinetic theory of gases. This is



**Notes**



## Notes

named as the Langmuir adsorption isotherm. This isotherm is based on the assumption that every adsorption site is equivalent and that the ability of a particle to bind there is independent of whether or not nearby sites are occupied. In his derivation, Langmuir considered adsorption to consist of the following two opposing processes :

Adsorption of the gas molecules on the surface of the solid.

Desorption of the adsorbed molecules from the surface of the solid.

Langmuir believed that eventually a dynamic equilibrium is established between the above two opposing processes. He also assumed that the layer of the adsorbed gas is only one molecule thick i.e., unimolecular. Since such type of adsorption is obtained in the case of **chemisorption**. Langmuir adsorption isotherm works particularly well for chemisorption.

The Langmuir adsorption isotherm is represented by the relation.

$$\frac{x}{m} = \frac{a p}{1 + b p} \quad \dots(15.1)$$

where  $a$  and  $b$  are two Langmuir parameters. At very high pressure, the above isotherm acquires the limiting form.

$$\frac{x}{m} = \frac{a}{b} \quad (\text{at very high pressure}) \quad \dots(15.2)$$

At very low pressure, Eq. (15.1) is reduced to  $x/m = ap$  (at very low pressure)  $\dots(15.3)$

In order to determine the parameters  $a$  and  $b$ , Eq. (15.1) may be written in its inverse form:

$$\frac{m}{x} = \frac{1 + b p}{a p} = \frac{b}{a} + \frac{1}{a p} \quad \dots(15.4)$$

A plot of  $m/x$  against  $1/p$  gives a straight line the slope and intercept equal to  $1/a$  and  $b/a$ , respectively. Thus, both parameters can be determined.

The Langmuir isotherm, in the form of Eq. (15.1) is generally more successful in interpreting the data than the Freundlich isotherm when a monolayer is formed. A plot of  $x/m$  versus  $p$  is shown in (Fig15.7). At low pressures, according to Eq. (15.3), pressure  $x/m$  increases linearly with  $p$ . At high pressure according to Eq. (15.2),  $x/m$  becomes constant i.e. the surface is fully covered and change in pressure has no effect and no further adsorption takes place, as is evident from Fig. 15.7.

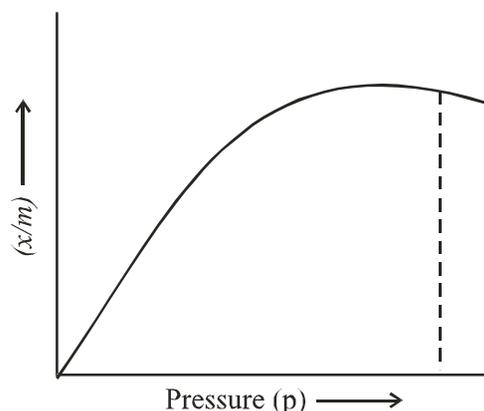


Fig. 15.7 : Langmuir Adsorption isotherm.

### (ii) Adsorption from Solutions.

Adsorption occurs from solutions also. The solute gets adsorbed on the surface of a solid adsorbent. Charcoal, a good adsorbent, is often used to adsorb acetic acid, oxalic acid and organic dyestuffs from their aqueous solutions.

The extent of adsorption,  $\frac{x}{m}$  depends upon the concentration  $c$  of the solute.

Freundlich isotherm is applicable to adsorption from solutions when concentration is used in place of pressure as shown below.

$$\frac{x}{m} = k c^{\frac{1}{n}}$$

and in the logarithmic form as

$$\log \frac{x}{m} = \log k + \frac{1}{n} \log c$$

The plot of  $\log \frac{x}{m}$  against  $c$  is also a straight line, provided very low and very high concentrations are avoided.

### 15.1.6 Applications of Adsorption

The phenomenon of adsorption finds many applications, some of which are given below:

1. Activated charcoal is used in gas masks in which toxic gases are adsorbed and air passes through it.
2. Silica gel packed in small cloth bags is used for adsorbing moisture in bottles of medicine and in small electronic instruments.
3. Animal charcoal is used for decolourizing many compounds during their manufacture.



Notes



Notes

- In chromatography, the selective adsorption of different solutes on the surface of solid adsorbent helps in their separation.
- Mordants are used during dyeing process with certain dyes. In such cases, the mordants fix the dye on the fabric by adsorption.



## INTEXT QUESTIONS 15.1

- Indicate which of the following statements are true or false. (T/F)
  - More easily liquifiable gases are adsorbed more strongly.
  - Non-porous adsorbents would adsorb more quantity of a gas than porous adsorbents under similar conditions.
  - The extent of adsorption increases with rise in temperature.
  - Chemisorption is highly specific in nature.
  - Adsorption can occur from solutions also.

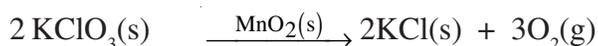
## 15.2 CATALYSIS

When hydrogen and oxygen gases are kept in contact with each other, no observable reaction occurs. If we add a small piece of platinum gauge in the mixture of these gases, the reaction occurs readily. Here platinum gauge speeds up the reaction and is called a **catalyst**.

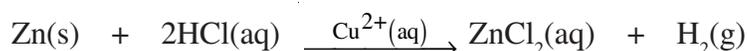
**A catalyst is a substance which changes the rate of a reaction but remains chemically unchanged at the end of the reaction.**

The phenomenon of change of reaction rate by addition of a substance which itself remains unchanged chemically is called **catalysis**. The following are some more examples of catalysis:

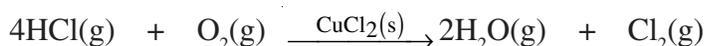
- Decomposition of potassium chlorate occurs at high temperature. If a small amount of the manganese dioxide is added, the decomposition occurs at much lower temperature. Here, manganese dioxide acts as catalyst.



- The evolution of hydrogen by the reaction between zinc and hydrochloric acid is catalysed by  $\text{Cu}^{2+}(\text{aq})$  ions.

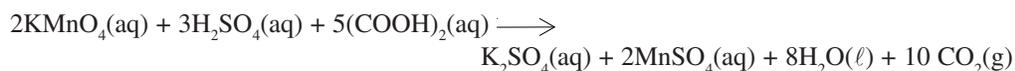


- The oxidation of hydrogen chloride gas by oxygen occurs more quickly if the gases are passed over cupric chloride.



**Auto-catalysis**

In certain reactions, one of the products of the reaction acts as the catalyst. For example, the oxidation of oxalic acid by acidified potassium permanganate occurs as



At room temperature, the reaction is quite slow in the beginning. Gradually it becomes fast due to the catalytic action of  $\text{Mn}^{2+}$  ions which are one of the products as  $\text{MnSO}_4$  in the reaction.

*The phenomenon in which one of the products of a reaction acts as a catalyst is known as auto-catalysis.*

**Negative Catalysis**

Some catalysts retard a reaction rather than speed it up. They are known as negative catalysts. For example :

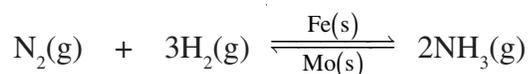
- (i) Glycerol retards the decomposition of hydrogen peroxide.
- (ii) Phenol retards the oxidation of sulphurous acid.

**Promoters and Poisons**

Certain substances increase or decrease the activity of the catalyst, although, by themselves they do not show any catalytic activity.

*The substances which increase the activity of a catalyst are called **promoters** and those which decrease the activity of a catalyst are called **poisons**.* For example:

- (i) In Haber's process for the manufacture of ammonia, the catalytic activity of iron is enhanced by molybdenum which acts as promoter.



- (ii) Copper promotes the catalytic activity of nickel during hydrogenation of oils.
- (iii) In Haber's process the catalyst iron is poisoned by hydrogen sulphide  $\text{H}_2\text{S}$ .
- (iv) In contact process for the manufacture of sulphuric acid, the catalyst platinum is poisoned by even the traces of arsenious oxide  $\text{As}_2\text{O}_3$ .

**15.2.1 General Characteristics of a Catalyst**

The following are the general characteristics of a catalyst :

- (i) A catalyst remains unchanged at the end of the reaction.



Notes



## Notes

The amount and the chemical composition of a catalyst remain unchanged in a catalytic reaction. However, the catalyst may undergo a physical change. For example, manganese dioxide, which is used as a catalyst in thermal decomposition of potassium chlorate becomes powder during the course of the reaction.

(ii) *A small quantity of the catalyst is generally enough.*

In most of the reactions, only a minute amount of catalyst is required. Only one gram of  $\text{Cu}^{2+}$  ions is sufficient to catalyse the oxidation of  $10^9$  litres of sodium sulphite solution. In some cases, the rate of reaction is directly proportional to the concentration of catalyst present. Catalysis by acids or bases is usually of this type.

(iii) *A catalyst does not alter the position of equilibrium state of a reversible reaction.*

A catalyst allows the equilibrium to be reached faster. However, it does not alter the equilibrium composition of the reaction mixture. It is because, a catalyst increases the rates of forward and backward reaction equally.

(iv) *Catalysts are generally specific in their action.*

Generally, one catalyst will change the rate of only one reaction. For example, manganese dioxide catalyses the decomposition of potassium chlorate but not of potassium perchlorate.

(v) *A catalyst cannot initiate a reaction.*

A catalyst can change the rate of a reaction which occurs even in the absence of catalyst. It cannot start a reaction.

(vi) *The activity of a catalyst can be increased by the presence of promoters and decreased by the presence of poisons.*

Presence of a promoter increases the activity of a catalyst, while the presence of a poison decreases it.

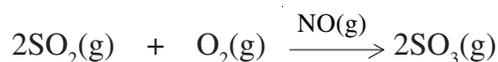
### 15.2.2 Homogeneous and Heterogeneous Catalysis

The phenomenon of catalysis can be divided into two main types – homogeneous and heterogeneous catalysis, on the bases of the number of phases present in the reaction mixture (A phase is a homogeneous part of a system).

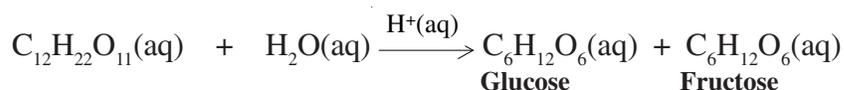
(a) *Homogeneous Catalysis*

*When the catalyst is present in the same phase as the reactants, the phenomenon is called **homogeneous catalysis**.* For example :

(i) Nitric oxide catalyses the oxidation of sulphur dioxide to sulphur trioxide in the lead chamber process.



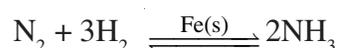
(ii) Hydrogen ions catalyse the *inversion of cane sugar*



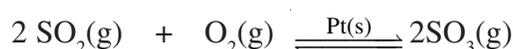
### (b) Heterogeneous Catalysis

When the catalyst is present in a phase other than that of reactants the phenomenon is called **heterogeneous catalysis**. For example :

(i) Iron (s) catalyses the formation of  $\text{NH}_3$  gas.

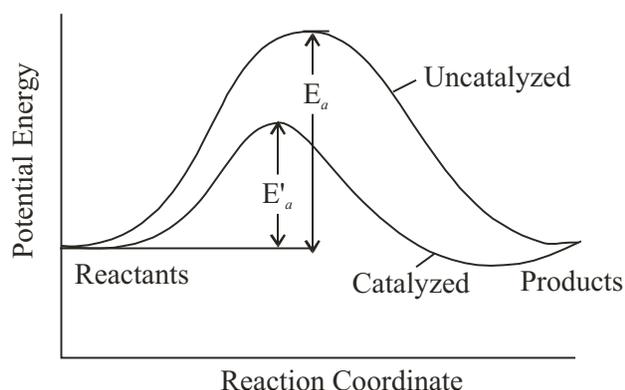


(ii) In contact process for the manufacture of sulphuric acid, platinized asbestos is used as the catalyst



### 15.2.3 Catalysis and Activation Energy

We have seen that a catalyst increases the rate of a reaction. We explain it by considering the Fig 15.8.



**Fig. 15.8 :** Graphical representation of the effect of catalyst on a reaction.

In this figure  $E_a$  is the activation energy of uncatalysed reaction and  $E'_a$  is the activation energy of the catalysed reaction. A catalyst lowers the activation energy as you can see in the figure ( $E'_a < E_a$ ). The reduction in activation energy is achieved by providing an alternative pathway of lower energy for the reaction.

You can also see in this figure that the relative energies of reactants and products are not changed. The enthalpy change is the same for the catalysed and uncatalysed reactions.



Notes



Notes



## INTEXT QUESTIONS 15.2

- List any two characteristics of a catalyst.
- A small amount of alcohol when added to a solution of sodium sulphite slows down its oxidation to sodium sulphate. What type of catalyst is alcohol?
- How would the activation energy be affected in the above reaction (given in Q.No.2) on adding the alcohol?
- Addition of molybdenum enhances the catalytic activity of iron in the Haber's process for the manufacture of ammonia. What are the substances like molybdenum called?



## WHAT YOU HAVE LEARNT

- The phenomenon of attracting and retaining the molecules of a gas or of a dissolved substance on the surface of a solid is called adsorption.
- The substance which gets adsorbed is called the adsorbate and the solid substance which adsorbs is called the adsorbent.
- The substances that are porous in nature and have rough surfaces are better adsorbent.
- Easily liquifiable gases are more readily adsorbed.
- Extent of adsorption decreases with rise in temperature and increases with the increase in pressure of the gas.
- Physical adsorption is due to van der Waal forces and chemisorption is due to forces similar to chemical bonds.
- Pressure dependence of adsorption of a gas at a constant temperature is given by Freundlich Adsorption Isotherm
 
$$\frac{x}{m} = k p^n$$
- A catalyst is the substance which changes the rate of a reaction, but itself remains chemically unchanged during the reaction.
- The catalysts which increase the rate of a reaction are called the positive catalysts while those which decrease the rate are called the negative catalysts.
- Auto catalysed reactions are those in which one of the products acts as the catalyst.

- A promoter enhances the activity of a catalyst while a poison hampers it.
- A catalyst can't initiate a reaction, nor can it alter the position of equilibrium state of a reversible reaction.
- When the catalyst is present in the same phase as the reactants it is called a homogeneous catalyst.
- When the catalyst is present in a phase other than that of reactants it is called a heterogeneous catalyst.
- A catalyst changes the rate of a reaction by changing its path and the activation energy.

**Notes****TERMINAL EXERCISE**

1. What is the difference between adsorption and absorption?
2. Distinguish between physical and chemical adsorption.
3. List the factors that affect adsorption.
4. What type of solids make better adsorbents?
5. Easily liquifiable gases are adsorbed more readily. Explain.
6. What is 'extent of adsorption'?
7. How does extent of adsorption vary with temperature in case of (i) physical adsorption and (ii) chemisorption? Depict graphically.
8. What is enthalpy of adsorption?
9. Explain the effect of temperature on extent of physical adsorption with the help of Le Chatelier's Principle.
10. What is an adsorption isotherm?
11. State mathematically Freundlich Adsorption Isotherm and depict it graphically. Under what conditions is it applicable.
12. Give the mathematical equation of Freundlich Isotherm for adsorption of solutes from solutions.
13. Give any three applications of adsorption.
14. What is a (i) catalyst and (ii) negative catalyst?
15. What are promoters and poisons? Give one example of each.

**Notes**

16. What is auto catalysis. Give one example.
17. Give any five characteristics of catalysis.
18. Distinguish between homogeneous and heterogeneous catalysis.
19. Give two examples each of homogeneous and heterogeneous catalysis.
20. How does a catalyst change the rate of reaction. Explain with the help of appropriate example.

**ANSWERS TO THE INTEXT QUESTIONS****15.1**

(i) T, (ii) F, (iii) F, (iv) T, (v) T

**15.2**

1. See text section 15.2.1
2. Negative catalyst
3. Increase
4. Promoters