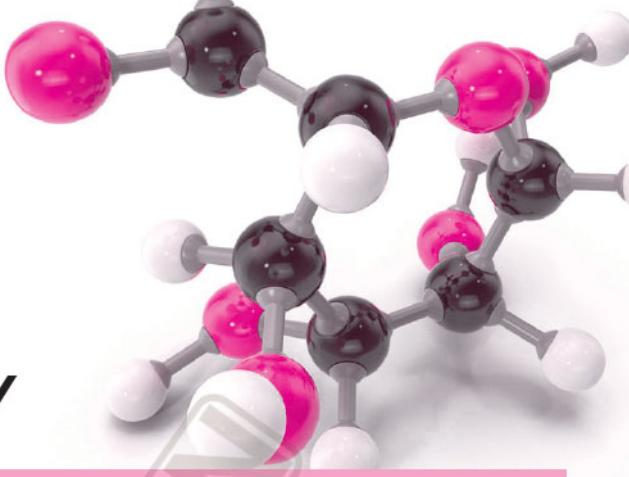




SURFACE CHEMISTRY



OBJECTIVES

Building on....

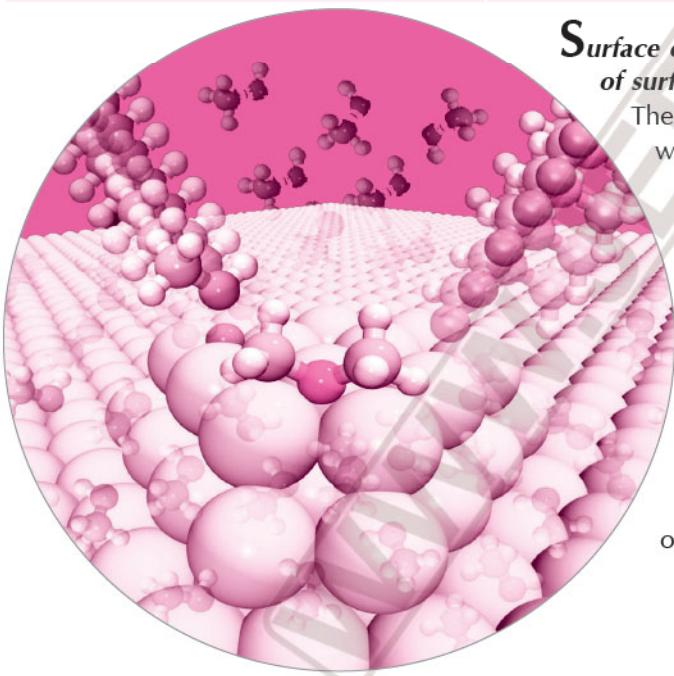
| | |
|---|-----------|
| ◆ Understanding Text | 1 |
| ◆ Conceptual Questions | 24, 47 |
| CHAPTER SUMMARY & QUICK CHAPTER ROUND UP | 50 |
| NCERT FILE | |
| ◆ In-text Qs & Exercises with Solutions | 53 |
| ◆ NCERT Exemplar Problems with Answers & Solutions (Subjective) | 55 |

Assessing....

| | |
|--|-------------|
| ◆ Quick Memory Test with Answers | 57 |
| ◆ HOTS & Advanced Level Questions with Answer | 58 |
| REVISION EXERCISES | |
| (with Previous Years' CBSE Qs & Other State Boards Qs) | 60 |
| ◆ Hints & Answers for Revision Exercises | 64 |
| UNIT PRACTICE TEST | 6/61 |

Preparing for Competition....

| | |
|---|-----------|
| ◆ Additional Useful Information | 65 |
| ◆ Topicwise MCQs | 65 |
| ◆ Competitive Examination Qs | |
| ➤ AIPMT & Other State Boards' Medical Entrance | 67 |
| ➤ JEE (Main) & Other State Boards' Engineering Entrance | 68 |
| ➤ JEE (Advance) for IIT Entrance | 70 |
| ◆ NCERT Exemplar Problems (Objective Questions) | 74 |
| ◆ Hints & Explanations for Difficult Questions | 79 |



Surface chemistry is the branch of chemistry which deals with the nature of surfaces and the phenomena that occur at the surfaces or interfaces.

There are many properties of substances particularly of solids and liquids, which depend upon the nature of the surface. Surface represents the boundary which separates two bulk phases. This is also called interface and is generally represented by separating the bulk phases by a hyphen or a slash. For example, the interface or surface between a solid and a liquid may be represented by solid-liquid or solid/liquid interface. There is no interface between gases because they are completely miscible.

Adsorption on solid or on solution surfaces, colloidal properties, electrode processes, heterogeneous catalysis, dissolution and crystallisation, corrosion etc. are important surface effects which are useful to understand many physical and chemical properties of the substances.

ADSORPTION

There are many examples which show that the surface of a solid has a tendency to attract and retain the molecules of the phase with which it comes into contact. These molecules, however, remain only at the surface of the solid and do not penetrate into the bulk. For example, when a small amount of finely divided charcoal is put into vessel containing a gas, it is observed that the pressure of the gas decreases rapidly at first and then gradually. The decrease in pressure of the gas is due to the accumulation of the gas on the surface of charcoal. It has been observed that the gas molecules remain only on the surface and do not penetrate into the bulk of the solid. Since these molecules remain only at the surface and do not go deeper into the bulk, their concentration is more at the surface than in the bulk of the solid. Thus,

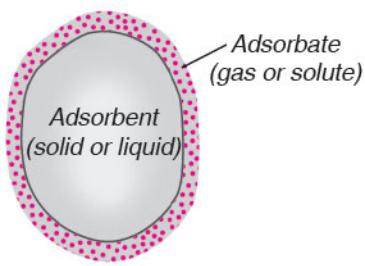


Fig. 1. Adsorbent and adsorbate.

the phenomenon of attracting and retaining the molecules of a substance at the surface of a solid or a liquid resulting into higher concentration of the molecules on the surface than in the bulk is called **adsorption**.

As a result of adsorption, there is decrease of surface energy.

Adsorbent and Adsorbate

The solid substance on the surface of which adsorption occurs is known as **adsorbent**.

The substances that get adsorbed on the solid surface due to intermolecular attractions are called **adsorbate**. The process of removal of an adsorbed substance from the surface on which it is adsorbed is called **desorption**. It is reverse of adsorption and can be brought about by heating or by reducing the pressure.

The phenomenon of adsorption of gases on the surface of metals is called occlusion.

The adsorbent may be a solid or a liquid and the adsorbate may be a gas or a solute in some solution.

Examples of adsorption

1. Adsorption of a gas by charcoal. If a gas like ammonia, sulphur dioxide, chlorine, oxygen, hydrogen, carbon monoxide or phosgene is taken in a closed vessel containing powdered charcoal, it is observed that the pressure of the gas **decreases**. The gas molecules concentrate at the surface of the charcoal i.e., gases are adsorbed at the surface. In this case, *charcoal acts as an adsorbent while gas molecules act as adsorbate*.

Solids particularly, finely divided have a large surface area and therefore, they show the property of adsorption to a much larger extent. For example, charcoal, silica gel, alumina gel, clay, colloids, metals in finely divided state, etc. are highly good adsorbents because they have highly porous structures and hence large surface area.

2. Adsorption of a dye by charcoal. When animal charcoal is shaken with a solution of an organic dye such as methylene blue it is observed that the solution turns colourless. The discharge of the colour is due to the fact that the coloured component (generally an organic dye) gets adsorbed on the surface of animal charcoal. Therefore, animal charcoal is used for decolourising a number of organic substances in the form of their solutions.

3. When aqueous solution of raw sugar (which has yellowish brown colour) is passed over beds of animal charcoal, it becomes colourless because the colouring substances are adsorbed by the charcoal.

4. The air becomes dry in the presence of silica gel because the water molecules get adsorbed on the silica gel.

Difference between Adsorption and Absorption

The terms *adsorption* and *absorption* are different. Adsorption is a phenomenon in which there is higher concentration of another substance on the surface than in the bulk. On the other hand *absorption* is a phenomenon in which the molecules of a substance are uniformly distributed throughout the body of other substance.

Thus, adsorption of substance A by B means that A is present on the surface of B and the concentration of A in parts of B away from the surface is negligible. On the other hand, absorption of A by B means that A is uniformly distributed over B. For example, when a stick of chalk is dipped in ink, the surface retains the colour of ink due to adsorption of coloured molecules. On the other hand, the solvent of the ink goes deeper into the stick due to absorption. When chalk stick is broken, it is found

to be white from inside.

The distinction between adsorption and absorption can be made by taking the example of water vapour. When silica gel is placed in the environment of water, it adsorbs the water vapour. As shown in Fig. 2 (a), the water vapours are present in high concentration at the surface of silica gel. On the other hand, when anhydrous calcium chloride is placed in the environment of water, it absorbs water. The water vapours uniformly get distributed throughout the body of calcium chloride as shown in Fig. 2(b).

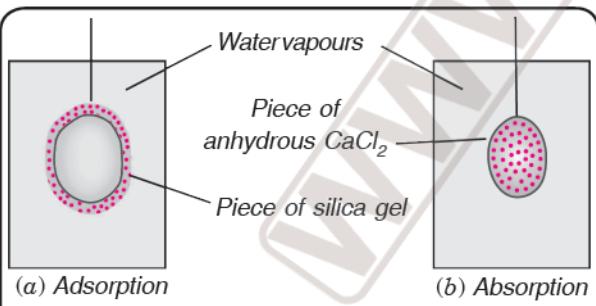


Fig. 2. Phenomena of adsorption and absorption.

REMEMBER

- Silica gel **adsorbs** water vapour while
- anhydrous calcium chloride **absorbs** water.

Thus, silica gel **adsorbs** water vapour while anhydrous calcium chloride **absorbs** water. Similarly, when ammonia gas is placed in contact with charcoal, it gets adsorbed on the charcoal.

Thus, adsorption is a surface phenomenon while absorption is a bulk property.

The **important points of distinction** between adsorption and absorption are:

| Absorption | Adsorption |
|---|---|
| 1. It is the phenomenon in which the particles of gas or liquid get uniformly distributed throughout the body of the solid. | It is the phenomenon of higher concentration of particles of gas or liquid on the surface than in the bulk of the solid. |
| 2. The concentration is the same throughout the material. Therefore, it is a bulk phenomenon. | The concentration on the surface of the adsorbent is different from that in the bulk. Therefore it is a surface phenomenon. |
| 3. Absorption occurs at uniform rate. | Adsorption is rapid in the beginning and its rate slowly decreases. |

Sorption. In some cases, both absorption and adsorption occur together and are not distinguishable. In such cases, the substance gets uniformly distributed into the bulk of the solid but at the same time, its concentration is higher at the surface than in the bulk. Such a phenomenon is called **sorption**.

Positive and Negative Adsorption

Positive adsorption. When the concentration of adsorbate is more on the surface of adsorbent relative to its concentration in the bulk, it is called **positive adsorption**.

Negative adsorption. When the concentration of the adsorbate is less on the surface relative to its concentration in the bulk, it is called **negative adsorption**. For example, in case of some liquid solutions, it is observed that the concentration of the solute is less on the surface than in the bulk of the solution. This type of adsorption is called negative adsorption.

For example, when a concentrated solution of potassium chloride (KCl) is shaken with blood charcoal; it shows positive adsorption but with a dilute solution of KCl, it shows negative adsorption.

Mechanism of Adsorption

Adsorption is a surface phenomenon, it arises because of the unbalanced forces on the surface of solids and liquids. This is because of the fact that the surface particles of the adsorbent (solid or liquid) are not in the same environment as the particles inside the bulk. If we consider a solid, it is observed that a molecule present in the bulk of the solid is being uniformly attracted from all sides by the neighbouring molecules [Fig. 3 (a)]. As a result, there is no net pull on this molecule. However, a molecule which lies near the surface (known as a surface molecule) is being attracted only by molecules below it. This is because there are no molecules above it. Therefore, surface molecules experience a resultant downward attractive force within the solid. In other words, the surface is under strain or tension due to unbalanced forces. Similar inward forces of attraction exist on the surface of a liquid. As a result, the surface of the solid or liquid tends to satisfy their residual forces by attracting and retaining the molecules of other species (a gas or dissolved substance) when brought in contact with them [Fig. 3 (b)].

Thus, the unbalanced forces of the adsorbent are responsible for attracting the adsorbate particles on its surface resulting in adsorption. The extent of adsorption increases with the increase of surface area per unit mass of the adsorbent at given temperature and pressure.

Illustration of adsorption, absorption and sorption

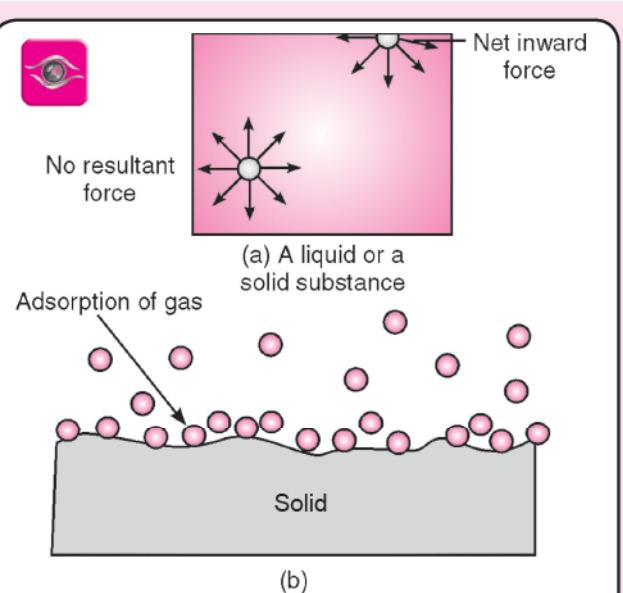
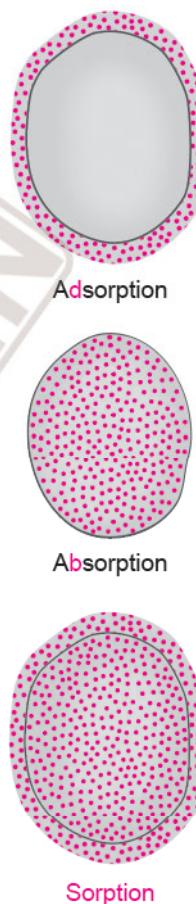


Fig. 3. (a) Inward forces at the surface of a solid or a liquid. (b) Adsorption of a gas at the solid surface.

TYPES OF ADSORPTION

Depending upon the nature of forces which hold the molecules of the adsorbate on the surface of the adsorbent, the adsorption is classified into two types :

1. Physical adsorption and
2. Chemical adsorption.

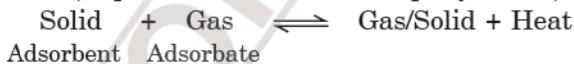
1. Physical adsorption

When the particles of the adsorbate are held to the surface of the adsorbent by the physical forces such as van der Waals forces, the adsorption is called physical adsorption or physisorption (short name for physical adsorption). The attractive forces are weak and, therefore, these can be easily overcome either by increasing the temperature or by decreasing the pressure. In other words, physical adsorption can be easily reversed or decreased.

Characteristics of physical adsorption

(i) **Low enthalpy of adsorption.** The attractive forces between adsorbent and the adsorbate molecules are weak (van der Waals forces) and therefore, molar enthalpy of adsorption is low and is of the order of $20\text{--}40 \text{ kJ mol}^{-1}$.

(ii) **Reversible nature.** The physical adsorption process is generally reversible and therefore, equilibrium is reached rapidly. Thus,



Applying Le Chatelier's principle, when we increase the pressure (or decrease the volume), the equilibrium shifts in the forward direction i.e. adsorption increases. Therefore, more of gas is adsorbed when pressure is increased as the volume of the gas decreases. Alternatively, gas can be removed by decreasing the pressure.

(iii) **Effect of temperature.** Since adsorption process is exothermic, therefore, physical adsorption occurs readily at low temperature and decreases with increase in temperature according to Le-Chatelier's principle. If the temperature is increased, the kinetic energy of the gas molecules increases and they leave the surface of the adsorbent. Therefore, *rise in temperature decreases the extent of adsorption*.

(iv) **Lack of specificity.** It is not specific in nature and therefore, all gases are adsorbed on all solids to the same extent. This is because a given surface of an adsorbent does not show any preference for a particular gas as the van der Waals forces are universal.

(v) **Nature of adsorbate.** The extent of physical adsorption depends upon the ease of liquefaction of the gas. The gases which are easily liquefied (i.e., having higher critical temperatures) are adsorbed readily because van der Waals forces are stronger near the critical temperatures. For example, 1g of activated charcoal adsorbs more SO_2 (critical temperature 630 K) than methane (critical temperature 190 K) which is still more than 4.5 mL of dihydrogen (critical temperature 33 K).

(vi) **State of adsorbate.** In physical adsorption, the state of adsorbate is same as in the bulk.

2. Chemical adsorption.

When the molecules of the adsorbate are held to the surface of the adsorbent by the chemical forces or chemical bonds, the adsorption is called chemical adsorption or chemisorption (short name for chemical adsorption).

In this case, a chemical reaction occurs between the adsorbed molecules and the adsorbent on the surface. This type of adsorption is irreversible. Like chemical reactions, there are activation energies for chemisorption.

Characteristics of chemical adsorption

(i) **Enthalpy of adsorption.** Attractive forces between adsorbent and adsorbate molecules are strong chemical bonds and therefore, molar heat of adsorption is high and is of the order of $80\text{--}240 \text{ kJ mol}^{-1}$.

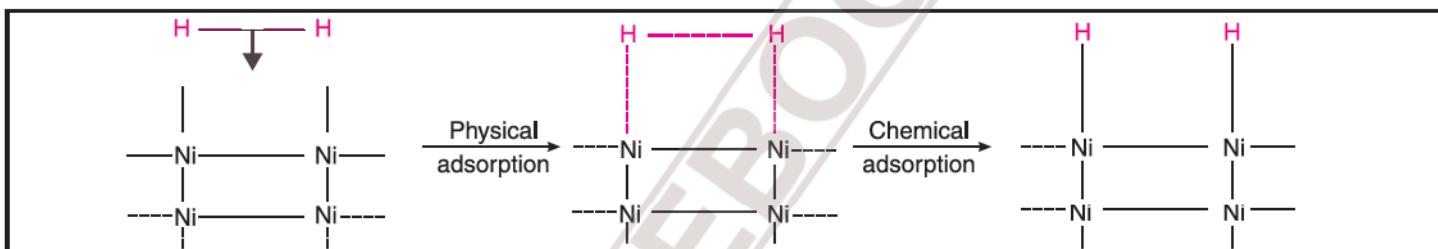
(ii) **Irreversible nature.** Unlike physical adsorption, it is irreversible because chemisorption involves compound formation.

(iii) **Effect of temperature.** Chemical adsorption first increases with increase in temperature upto a certain extent and then decreases regularly. A gas adsorbed at low temperature by physical adsorption may change into chemisorption at a high temperature. For example, hydrogen is first adsorbed on nickel by van der Waals forces. Molecules of hydrogen then dissociate to form hydrogen atoms which are held on the surface by chemisorption. Usually high pressure is also favourable for chemisorption.

(iv) **High selectivity.** Unlike physical adsorption, chemical adsorption involves the formation of chemical bonds between the adsorbed molecules and the surface of adsorbent. Therefore, it is highly selective. In other words, chemical adsorption depends upon the nature of the chemical properties of the gas and the adsorbent. For example, oxygen is adsorbed on metals by virtue of oxide formation and hydrogen is adsorbed by transition metals due to hydride formation.

(v) **State of adsorbed species.** Since chemical reaction takes place in this type of adsorption, therefore, the state of adsorbed molecules may be different from that in the bulk. For example, oxygen exists as O_2 in the bulk but on the surface it may exist as O_2^- , O_2^{2-} , O , O^- , O^{2-} , etc.

Explanation of chemisorption. Let us consider the example of adsorption of H_2 gas on the surface of nickel or platinum. Due to unbalanced forces on the surface of the solid, the hydrogen molecules are attracted towards it by weak van der Waals force and hence get adsorbed on it. The adsorbed molecules then dissociate into atoms and are chemisorbed and hence are held strongly.



Since chemical adsorption needs some activation energy, the process is also called **activated adsorption**.

Enthalpy of adsorption

The amount of heat evolved when one mole of an adsorbate (gas or liquid) is adsorbed on the surface of an adsorbent is called **enthalpy of adsorption**.

The enthalpy of adsorption for chemisorption is larger than that for physical adsorption. For example, the enthalpy of adsorption for chemisorption is almost of the same magnitude as of chemical reactions of the order of $80\text{--}240\text{ kJ mol}^{-1}$. On the other hand, the enthalpy of adsorption for physical adsorption is of the order of heat of condensation of vapours into liquids i.e., about $20\text{--}40\text{ kJ mol}^{-1}$.

Gibbs energy change during adsorption

During adsorption, there is always decrease in residual forces of the surface i.e., there is decrease in surface energy, which appears as heat. Therefore, adsorption is an exothermic process and therefore, ΔH is negative for adsorption and favours the process. On the other hand, the molecules of the adsorbate (gas) are held on the surface of the adsorbent and, therefore, they have lesser tendency to move about freely. In other words, entropy decreases i.e., ΔS is negative and the entropy factor opposes the process. According to Gibbs Helmholtz equation,

$$\Delta G = \Delta H - T\Delta S, \text{ or } \Delta G = (-) - T(-)$$

Thus for the process of adsorption to occur, ΔG must be negative, which is possible only when $\Delta H > T\Delta S$ in magnitude. Thus, for adsorption to be spontaneous, ΔH should have sufficiently high negative value so that ΔG becomes negative. This is true in the beginning. However, as the adsorption continues, ΔH becomes less and less negative and $T\Delta S$ keeps on increasing and ultimately ΔH becomes equal to $T\Delta S$ so that ΔG becomes zero. This state is called **adsorption equilibrium**.

REMEMBER

- $\Delta H_{\text{adsorption}}$ is always $-ve$
- $\Delta S_{\text{adsorption}}$ is $-ve$
- For process of adsorption to occur i.e., ΔG to be $-ve$, ΔH must be $> T\Delta S$.
- i.e., ΔH should have sufficiently high value ($> T\Delta S$) so that ΔG becomes negative.

It may be noted that in **exceptional cases, chemisorption may be endothermic** (*i.e.*, $\Delta H = +ve$). For example, H_2 adsorbs on glass endothermally. In this case $H_2(g)$ splits into H atoms on glass as

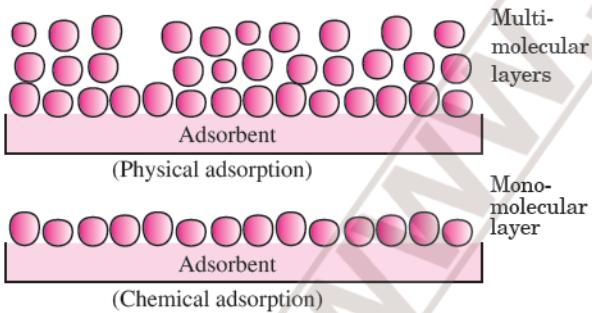


so that ΔS is sufficiently positive to overcome the small positive enthalpy change (*i.e.*, $T\Delta S > \Delta H$ so that $\Delta G = -ve$). Similarly, highly hydrated solutes, when adsorbed on solids also have positive ΔH . But these are accompanied by large positive ΔS due to release of water molecules on adsorption. Therefore, ΔG is also negative in these cases.

Differences between physical adsorption and chemical adsorption

The main points of differences between physical adsorption and chemical adsorption are summed up below :

| Physical adsorption | Chemical adsorption |
|---|--|
| 1. The forces between the adsorbate molecules and the adsorbent are weak van der Waals forces . | The forces between the adsorbate molecules and the adsorbent are strong chemical forces similar to chemical bonds. |
| 2. Low enthalpy of adsorption of the order of 20 to 40 kJ mol⁻¹ | High enthalpy of adsorption of the order of 80 to 240 kJ mol⁻¹ . |
| 3. Usually occurs at low temperature and decreases with increase of temperature . | It occurs at high temperature and increases with the increase of temperature . |
| 4. It is reversible in nature. | It is irreversible . |
| 5. The extent of adsorption depends upon the ease of liquefaction of the gas. More easily liquefiable gases are adsorbed readily. | There is no correlation between extent of adsorption and the ease of liquefaction of gas. It also depends on the nature of gas. Gases which can react with the adsorbent show chemisorption. |
| 6. It is not specific in nature <i>i.e.</i> , all gases are adsorbed on the surface of a solid to some extent. | It is highly specific in nature and occurs only when there is bond formation between adsorbent and adsorbate molecules. |
| 7. No appreciable activation energy is needed. | High activation energy is sometimes needed. |
| 8. The state of adsorbate is same as in the bulk. | State of adsorbate molecules may be different from that in the bulk. |
| 9. It forms multimolecular layers . | It forms mono-molecular layer . |
| 10. Rate of adsorption increases with increase in pressure of adsorbate . | Rate of adsorption usually decreases as the pressure increases . |
| 11. It depends on the surface area. It increases with an increase of surface area. | It also depends on surface area and also increases with an increase of surface area. |



Adsorption of N_2 on Iron

The behaviour of adsorption of N_2 on iron clearly distinguishes between physisorption and chemisorption. At 83 K, nitrogen is physisorbed on iron surface as N_2 molecules. The amount of N_2 adsorbed decreases rapidly as the temperature increases. At room temperature, practically, there is no adsorption of N_2 on iron. However at 773 K and above, nitrogen is chemisorbed on the iron surface as nitrogen atoms.

Types of Forces : As already discussed, the atoms or molecules of a solid surface have unbalanced or residual attractive forces. As a result, the surface of the solid has the tendency to attract the molecules of a gas or a liquid when they come in its contact. Since energy is released because of attraction, the solid gets a more stable state. The adsorbed atoms or molecules are held on the surface of a solid by physical van der Waals forces or chemical forces due to residual valence bonds.

The forces of attraction increase when a solid is broken into pieces or crushed to powder. This is because of formation of *more surfaces*. For example, when a solid substance is broken into two pieces, two new surfaces are formed

and therefore, the number of unbalanced forces become more (Fig. 4). As a result, the tendency for adsorption becomes large.

ADSORPTION OF GASES ON SOLIDS

Almost all solids adsorb gases to some extent. The extent of adsorption of a gas on a solid surface is affected by the following factors :

1. *Nature of the gas*
2. *Nature of adsorbent*
3. *Specific area of the adsorbent*
4. *Effect of temperature*
5. *Effect of pressure*
6. *Activation of adsorbent.*

These factors are discussed below :

1. Nature of the gas (or adsorbate). The amount of gas adsorbed by a solid depends on the nature of the gas. In general, under given conditions of temperature and pressure, the easily liquefiable gases such as CO_2 , HCl , NH_3 , Cl_2 , etc. are adsorbed more than the permanent gases such as H_2 , N_2 and O_2 .

The ease of liquefaction of a gas depends upon its critical temperature (T_c). The critical temperature of a gas is the minimum temperature above which a gas cannot be liquefied, however high the pressure may be applied. *The higher the critical temperature, the more easily a gas is liquefied and hence more readily it will be adsorbed* because the van der Waals forces are stronger near the critical temperatures. For example, 1 g of activated charcoal can adsorb the following amounts of gases :

| Gas | H_2 | N_2 | CO | CH_4 | CO_2 | NH_3 | SO_2 |
|-----------------------|--------------|--------------|-----|---------------|---------------|---------------|---------------|
| Critical temp. (K) | 33 | 126 | 134 | 190 | 304 | 406 | 430 |
| Amt. adsorbed (in mL) | 4.5 | 8.0 | 9.3 | 16.2 | 48 | 180 | 380 |

Critical temp. increases →
 Ease of liquefaction increases →
 Adsorption increases →

However, the chemical adsorption is highly specific in nature and a gas gets adsorbed on the solid only if it forms chemical bonds.

2. Nature of adsorbent. The extent of adsorption of a gas depends upon the nature of adsorbent. Activated charcoal can adsorb gases which are easily liquefied. Many poisonous gases are adsorbed by charcoal. Therefore, it is used in gas masks for adsorbing these poisonous gases. Gases such as H_2 , N_2 and O_2 are generally adsorbed on finely divided transition metals e.g., Ni and Co. Most common adsorbents used are activated charcoal, finely divided metals, metal oxides (silica gel, aluminium oxide, etc.), and clay. Each of these have their characteristic adsorption properties.

3. Surface area of the adsorbent. The extent of adsorption increases with the increase in the surface area of the adsorbent. The larger the surface area of the solid, the greater would be its adsorbing capacity. Therefore, the porous

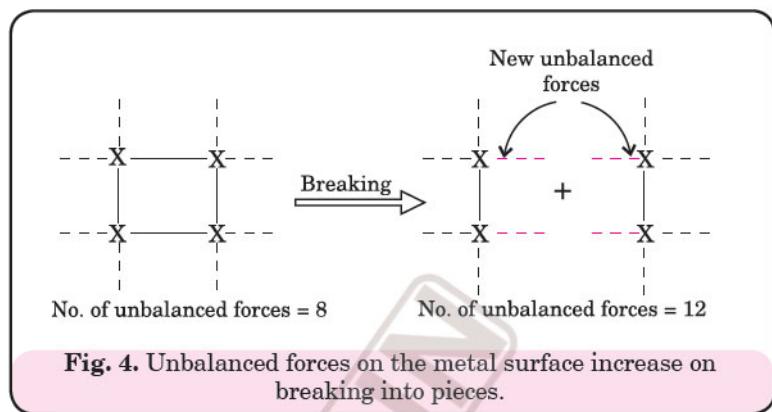


Fig. 4. Unbalanced forces on the metal surface increase on breaking into pieces.

REMEMBER

Higher the critical temperature of a gas, greater is the amount of that gas adsorbed.

and finely divided forms of adsorbents adsorb large quantities of adsorbate. However, the pores of the adsorbent should be large enough to allow the gas molecules to enter them.

4. Effect of temperature. The process of adsorption is an **exothermic** process and is invariably accompanied by evolution of heat. Like any other equilibrium, adsorption is a process involving a true equilibrium. The two opposing processes involved are *condensation* (*i.e.*, adsorption) of the gas molecules on the surface of the adsorbent solid and *evaporation* (*i.e.*, desorption) of adsorbed gas molecules from the solid surface into gaseous phase. Since the process of condensation is exothermic, the reverse process of evaporation is endothermic. The equilibrium may be expressed as :

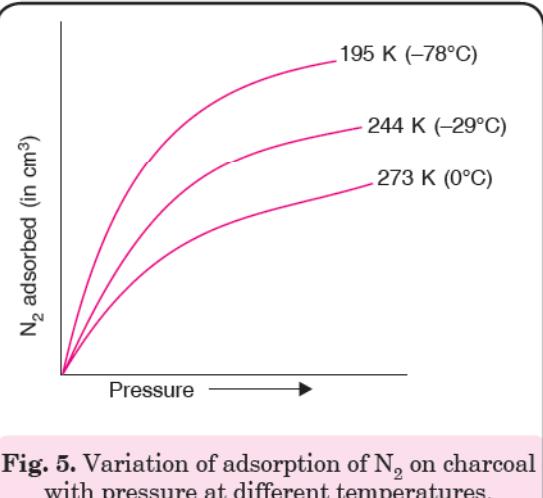
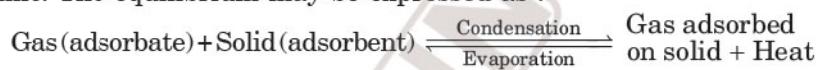


Fig. 5. Variation of adsorption of N_2 on charcoal with pressure at different temperatures.

According to Le-Chatelier's principle, the increase in temperature will favour the reverse process of desorption. Therefore, adsorption will decrease with increase in temperature and adsorption will be favoured by decrease in temperature. Thus, increase of temperature decreases adsorption and vice versa. For example, it has been observed that one gram of charcoal adsorbs about 10 cm^3 of N_2 at 273 K (0°C), but the same amount of charcoal adsorbs 20 cm^3 of N_2 at 244 K (-29°C) and about 45 cm^3 at 195 K (-78°C). This is shown in Fig. 5.

This is clear from the above figure that at a particular pressure, adsorption increases with decrease in temperature.

5. Effect of pressure. At a constant temperature, the adsorption of a gas increases with increase in pressure. This can also be explained on the basis of Le-Chatelier's principle. Adsorption of a gas leads to decrease in pressure and therefore, according to Le-Chatelier's principle, the magnitude of adsorption increases with increase in pressure. The variation of adsorption with pressure at different constant temperatures is shown in Fig 5.

Thus, **decrease of temperature and increase of pressure both tend to increase the extent of adsorption of a gas on a solid.**

6. Activation of adsorbent. Activation of adsorbent means increasing of the adsorbing power of the adsorbent. It is very necessary to increase the rate of adsorption. This can be done by the following methods :

(i) Metallic adsorbents are activated by making the surface of the adsorbent rough. This is done by mechanical rubbing or by subjecting them to some chemical reactions or by depositing finely dispersed metals on the surface of adsorbent by electroplating.

(ii) To increase the adsorbing power of adsorbents, they are sub-divided into smaller pieces. As a result, the surface area increases and therefore, the adsorbing power increases.

(iii) Some adsorbents are activated by strong heating in contact with superheated steam or in vacuum at a temperature of $623\text{--}1273\text{K}$ so that gases already adsorbed are removed. For example, charcoal is activated by subjecting it to the action of superheated steam.

ADSORPTION ISOTHERMS

As already learnt, the adsorption on a given surface generally increases with increase in pressure (for gases) and concentration (for solutions) at a constant temperature.

The extent of adsorption of a gas per unit mass of adsorbent depends upon the pressure of the gas. **The relation between the amount of substance adsorbed by the adsorbent and the equilibrium gas pressure (or concentration for solutions) at constant temperature** is called an **adsorption isotherm**. This may be expressed in the form of an equation or graphical curve (or plot). The extent of adsorption is usually expressed as $\frac{x}{m}$ where x is the mass of adsorbate and m is the mass of the adsorbent. The simplest type of adsorption is shown in Fig. 6.

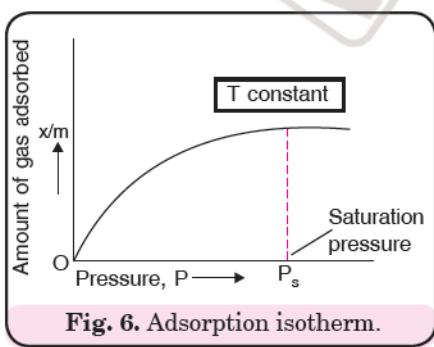


Fig. 6. Adsorption isotherm.

It is clear from the figure that extent of adsorption (x/m) increases with pressure and becomes maximum corresponding to pressure P_s , called equilibrium pressure. Since adsorption is a *reversible process*, the desorption also takes place simultaneously. At this pressure (P_s), the amount of gas adsorbed becomes equal to the amount of gas desorbed so that the extent of adsorption becomes constant even though the pressure is increased. This state is also called **saturation state** and P_s is called **saturation pressure**.

The scientists have tried to explain the adsorption in terms of some empirical mathematical relations called adsorption isotherms. The most common types are discussed below :

A. Freundlich Adsorption Isotherm

The variation of extent of adsorption (x/m) with pressure (P) at a particular temperature was given mathematically by Freundlich in 1909. From the adsorption isotherm (Fig. 6), the following observations can be easily made :

(i) **At low pressure**, the graph is almost straight line which indicates that x/m is directly proportional to pressure (Fig. 7). This may be expressed as :

$$\frac{x}{m} \propto P \text{ or } \frac{x}{m} = kP \quad \dots(i)$$

where k is a constant.

(ii) **At high pressure**, the graph becomes almost constant which means that x/m becomes independent of pressure (Fig. 7). This may be expressed as :

$$\frac{x}{m} = \text{constant} \quad \text{or} \quad \frac{x}{m} \propto P^0 \quad (\because P^0 = 1)$$

$$\text{or} \quad \frac{x}{m} = kP^0 \quad \dots(ii)$$

(iii) **Thus, in the intermediate range of pressure**, x/m will depend upon the power of pressure which lies between 0 to 1 i.e., fractional power of pressure (probable range 0.1 to 0.5). This may be expressed as

$$\frac{x}{m} \propto P^{1/n}$$

$$\text{or} \quad \frac{x}{m} = k P^{1/n} \quad \dots(iii)$$

where n can take any whole number value which depends upon the nature of adsorbate and adsorbent. The above relationship is also called **Freundlich's adsorption isotherm** and is shown in Fig. 7.

Calculation of k and n of adsorption isotherm

The constants k and n can be determined as explained below :

Taking logarithms on both sides of Eq. (iii), we get

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

Thus, if we plot a graph between $\log (x/m)$ on y-axis (ordinate) and $\log P$, on x-axis (abscissa), straight line will be obtained. This also shows the validity of Freundlich isotherm. The slope of the line (Fig. 8) is equal to $1/n$ and the intercept is equal to $\log k$.

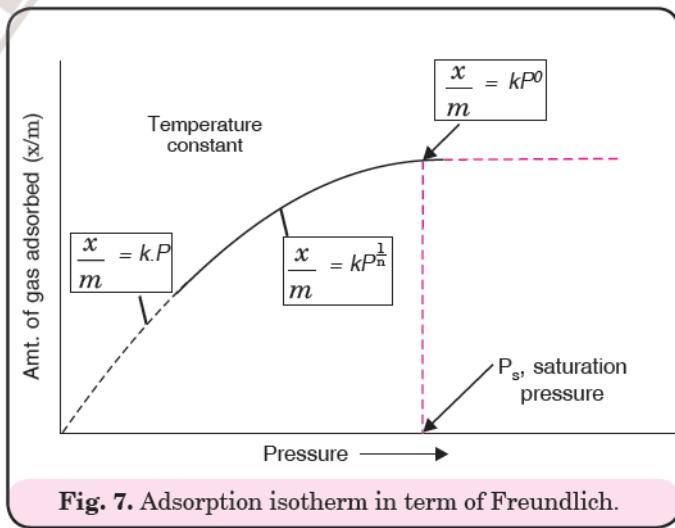


Fig. 7. Adsorption isotherm in term of Freundlich.

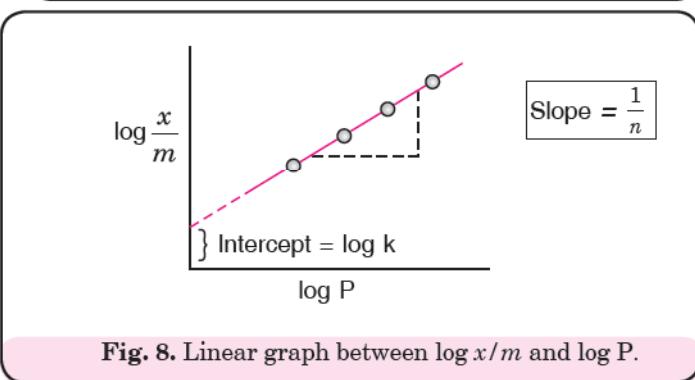


Fig. 8. Linear graph between $\log x/m$ and $\log P$.

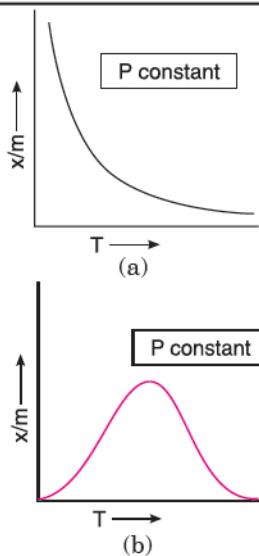


Fig. 9. Adsorption isobars for
(a) physical adsorption and
(b) chemical adsorption.

NOTE

We have learnt that increase in temperature tends to lower the extent of adsorption. Therefore, in order to get the same amount of adsorption at a higher temperature, the pressure of the system has to be increased. Hence, a straight line relationship between temperature and pressure is generally observed. *The graph showing the variation of pressure with temperature for a given amount of adsorption is called isostere.*

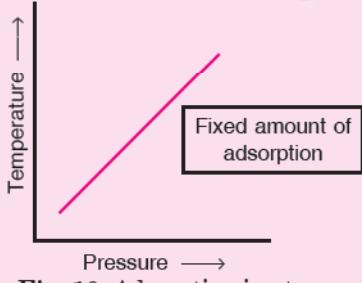


Fig. 10. Adsorption isostere.

Limitations of Freundlich adsorption isotherm

Freundlich adsorption isotherm fails at high pressure of the gas. Therefore, this relation is considered as approximate and is applicable only at low pressures. Irving Langmuir in 1916 derived a simple adsorption isotherm on the theoretical considerations based on *kinetic theory of gases*. This is named as **Langmuir adsorption isotherm**.

ADSORPTION ISOBARS

As we have learnt, with the increase in temperature at constant pressure, the extent of adsorption (x/m) will decrease. *The graph between extent of adsorption and temperature at constant pressure* is called **adsorption isobar**. However, this is true for physical adsorption as shown in Fig. 9 (a). In case of chemisorption, the adsorption initially increases with rise in temperature and then decreases as shown in Fig. 9 (b). This behaviour is expected because like all chemical reactions, some activation energy is required for chemisorption. At low temperature, x/m is small. As temperature is increased, the molecules of the adsorbate gain energy and become equal to activation energy so that proper bonds are formed with the adsorbent molecules. Therefore, initially amount of gas adsorbed increases with rise in temperature. Further increase of temperature will increase the energy of molecules which have already been adsorbed. This would increase the rate of desorption and, therefore, decrease the extent of adsorption.

The adsorption isobar graphs can be used to **distinguish** between physical and chemical adsorptions. In physical adsorption, there is a regular decrease as temperature increases. However, in chemisorption, there is initial increase and then it decreases [Fig. 9 (b)].

ADSORPTION FROM SOLUTIONS

The process of adsorption can take place from solutions also. For example, when solution of acetic acid in water is shaken with charcoal, a part of the acid is adsorbed by charcoal and therefore, the concentration of acetic acid decreases in the solution. Similarly, when magnesium is precipitated as magnesium hydroxide, in the presence of magneson reagent, it attains blue colour. The colour is due to adsorption of magneson. The litmus solution when shaken with charcoal becomes colourless because of adsorption from solution phase. It is also observed that solid adsorbents adsorb certain solutes from solution in preference to other solutes and solvents. For example, animal charcoal decolourises impure sugar solution by adsorbing colouring dye in preference to sugar molecules. The following observations are made in case of adsorption from solution phase :

- The extent of adsorption depends upon the concentration of the solute in the solution. It increases with increase in concentration of solute in the solution.
- The extent of adsorption decreases with increase of temperature.
- The extent of adsorption also depends upon the nature of adsorbent and adsorbate.
- The extent of adsorption increases with an increase in the surface area of the adsorbent.

The Freundlich's adsorption isotherms obtained for the adsorption of gases on the surface of solid adsorbents have been found to be approximately applicable to the adsorption of solutes from the solutions. Here, the equilibrium pressure in the adsorption of gases is replaced by the equilibrium concentrations (C) of the adsorbates in solution. The adsorption isotherm may be represented as :

$$\frac{x}{m} = k C^{1/n} \quad \dots(i)$$

Taking logarithms, Eq. (i) becomes

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

A graph between x/m and C has been found to be similar to one shown for x/m and P for gases on solid (Fig. 7). From the graph, the values of $1/n$ and $\log k$ can be calculated as slope and intercept respectively. The equation can be tested

experimentally by taking solutions of different concentrations of acetic acid. Equal volumes of solutions are added to equal volumes of charcoal in different flasks. After adsorption for a fixed time, the final concentration is determined in each

flask. The difference in the initial and final concentrations gives the value of x . Using the above equation, Freundlich adsorption isotherm can be verified.

SOLVED EXAMPLES

Example 1.

Three grams of oxygen are adsorbed on 1.2 g of charcoal powder at 300 K and 0.7 atm. Express the mass, number of moles and volume of oxygen at 300 K, 0.7 atm and at STP adsorbed per gram of the adsorbent.

Solution : Mass of adsorbate, $x = 3 \text{ g}$

Mass of adsorbent, $m = 1.2 \text{ g}$

Mass of adsorbate per gram of adsorbent

$$= \frac{x}{m} = \frac{3}{1.2} = 2.5 \text{ g}$$

No. of moles of adsorbate per gram of adsorbent

$$= \frac{2.5}{32} = 0.078$$

Volume of 2.5 g of O_2 at 300 K and 0.7 atm

$$\begin{aligned} &= \frac{nRT}{P} \\ &= \frac{0.078 \times 82.0 \times 300}{0.7} \\ &= 2741.1 \text{ cm}^3 \quad (\text{R} = 82.0 \text{ cm}^3 \text{ atm K}^{-1}) \end{aligned}$$

Volume of 2.5 g of O_2 at 273 K and 1 atm

$$= \frac{0.078 \times 82.0 \times 273}{1} = 1746.1 \text{ cm}^3$$

Example 2.

50 mL of 1 M oxalic acid (molar mass = 126) is shaken with 0.6 g of charcoal. The final concentration of the solution after adsorption has been found to be 0.4 M. Calculate the amount of oxalic acid adsorbed per gram of charcoal.

Solution: 1 M oxalic acid solution means 1 mole of oxalic acid or 126 g present in 1000 mL solution.

∴ 50 mL of 1M solution will contain oxalic acid

$$= \frac{126}{1000} \times 50 = 6.3 \text{ g}$$

Concentration of solution after adsorption = 0.4 M

1000 mL of solution contain oxalic acid = $0.4 \times 126 = 50.4 \text{ g}$
50 mL of solution will contain oxalic acid

$$= \frac{50.4}{1000} \times 50 = 2.52 \text{ g}$$

Amount of oxalic acid adsorbed by 0.6 g of charcoal

$$= 6.3 - 2.52 \\ = 3.78 \text{ g}$$

Amount of oxalic acid adsorbed per gram of charcoal

$$= \frac{3.78}{0.6} = 6.30 \text{ g}$$

Example 3.

1 g of charcoal adsorbs 100 mL of 0.5 M CH_3COOH to form a monolayer and thereby molarity of acetic acid is reduced to 0.49 M. Calculate the surface area of the charcoal adsorbed by each molecule of acetic acid. Surface area of charcoal = $3.01 \times 10^2 \text{ m}^2/\text{g}$ (I.I.T.2003)

Solution : No. of moles of acetic acid initially present

$$= \frac{0.5}{1000} \times 100 = 0.05 \text{ mol.}$$

No. of moles of acetic acid left after adsorption

$$= \frac{0.49}{1000} \times 100 = 0.049.$$

Moles of acetic acid adsorbed = $0.05 - 0.049 = 0.001 \text{ mol.}$

$$\text{or } = 1 \times 10^{-3} \text{ mol.}$$

No. of molecules of acetic acid adsorbed

$$\begin{aligned} &= 1 \times 10^{-3} \times 6.022 \times 10^{23} \\ &= 6.022 \times 10^{20} \text{ molecules} \end{aligned}$$

Now, 1 g of charcoal has area = $3.01 \times 10^2 \text{ m}^2$

∴ 6.022×10^{20} molecules of acetic acid gets adsorbed on surface area = $3.01 \times 10^2 \text{ m}^2$

∴ 1 molecule of acetic acid gets adsorbed on surface area

$$\begin{aligned} &= \frac{3.01 \times 10^2}{6.02 \times 10^{20}} \\ &= 5.0 \times 10^{-19} \text{ m}^2 \end{aligned}$$

Example 4.

20% surface sites have adsorbed N_2 . On heating N_2 gas is evolved from sites and were collected at 0.001 atm and 298 K in a container of volume 2.46 cm^3 . Density of surface sites is $6.023 \times 10^{14} \text{ cm}^{-2}$ and surface area is 1000 cm^2 . Calculate the number of surface sites occupied per molecule of N_2 . (I.I.T 2005)

Solution : For adsorbed N_2 on surface sites, $p(\text{N}_2) = 0.001$ atm, $V = 2.46 \text{ cm}^3$, $T = 298 \text{ K}$, $R = 82.0 \text{ atm cm}^3 \text{ K}^{-1} \text{ mol}^{-1}$

$$n(\text{N}_2) = \frac{pV}{RT} = \frac{0.001 \times 2.46}{82.0 \times 298} = 1.006 \times 10^{-7}$$

Molecules of N_2 adsorbed = $1.006 \times 10^{-7} \times 6.022 \times 10^{23}$
= 6.022×10^{16}

Total surface sites available = No. of sites per cm^2 × Area
= $6.023 \times 10^{14} \times 1000$
= 6.023×10^{17}

Surface sites on which N_2 is adsorbed

$$= \frac{6.023 \times 10^{17} \times 20}{100} \\ = 12.046 \times 10^{16}$$

No. of sites adsorbed per molecule of N_2

$$= \frac{12.046 \times 10^{16}}{6.023 \times 10^{16}} = 2$$

Example 5.

The following data were obtained for the adsorption of carbon monoxide gas on 3.0 g of charcoal at 0°C and 1 atm pressure.

| | | |
|---------------------------|------|------|
| Pressure (mm Hg) | 200 | 400 |
| Volume of gas adsorbed, x | 18.6 | 31.4 |
| (reduced to STP) | | |

Calculate the values of the constants k and n using Freundlich adsorption equation.

Solution : According to Freundlich adsorption isotherm,

$$\frac{x}{m} = kP^n$$

$$\text{or } \log \frac{x}{m} = \log k + \frac{1}{n} \log P$$

Substituting the values of the two given sets, we get

$$\log \frac{18.6}{3} = \log k + \frac{1}{n} \log 200 \quad \dots (i)$$

$$\log \frac{31.4}{3} = \log k + \frac{1}{n} \log 400 \quad \dots (ii)$$

Subtracting eqn. (i) from (ii) we get

$$\log \frac{31.4}{18.6} = \frac{1}{n} \log \frac{400}{200}$$

$$\text{or } \log 1.688 = \frac{1}{n} \log 2$$

$$\text{or } 0.2274 = \frac{1}{n} \times 0.3010$$

$$\therefore n = \frac{0.3010}{0.2274} = 1.32$$

Substituting the value of n in eqn. (i)

$$\log 6.2 = \log k + \frac{1}{1.32} \log 400$$

$$0.7924 = \log k + \frac{1}{1.32} \times 2.602$$

$$0.7924 = \log k + 1.9712$$

$$\log k = -1.1788 = \bar{2.8212}$$

$$k = \text{antilog} (\bar{2.8212}) = 0.0662 \text{ cm}^3 \text{ g}^{-1}$$

APPLICATIONS OF ADSORPTION

Some of the important applications of adsorption are given below :

1. In gas masks. Activated charcoal or a mixture of adsorbents is generally used in gas masks to adsorb poisonous and toxic gases from air. These masks are commonly used by the miners because there are poisonous gases like CO, CH₄, etc. in the atmosphere in the coal mines. Therefore, these masks help to purify the air for breathing.

2. In dyeing of cloth. Mordants such as alums are used in dyeing of cloth. They adsorb the dye particles which, otherwise, do not stick to the cloth.

3. In dehumidizers for control of humidity. Silica and aluminium gels are commonly used to adsorb humidity or moisture from air. This is necessary for storage of delicate instruments which might otherwise be damaged by moisture.

4. Removal of colouring matter from solutions. Many substances such as sugar, juice and vegetable oils are coloured due to the presence of impurities. They can be decolourised by placing in contact with adsorbents like *activated charcoal* or *fuller's earth*. This method is commonly used in the manufacture of cane sugar. The coloured sugar solution is treated with animal charcoal or activated charcoal.

5. Heterogeneous catalysis. The phenomenon of adsorption is useful in the heterogeneous catalysis. Adsorption of reactants on the solid surface of catalysts increases the rate of reaction. The metals such as Fe, Ni, Pt, Pd, etc. are used in the manufacturing process. Manufacture of ammonia using iron as catalyst (**Haber process**), manufacture of sulphuric acid by **Contact process** and use of finely divided nickel in the hydrogenation of oils are excellent examples of heterogeneous catalysis. Its use is based upon the phenomenon of adsorption.

6. In ion-exchange resins. The organic polymers containing groups like –COOH, –SO₃H and –NH₂, etc. possess the property of selective adsorption of ions from solutions. These are quite useful in the softening of water.

7. In adsorption indicators. Many adsorption indicators are being used in volumetric analysis e.g., dyes such as eosin and fluorescein are used as adsorption indicators. In these methods, the dyes are adsorbed on the surfaces of certain precipitates (such as silver halides) which give characteristic colour at the end point.

8. In qualitative analysis. Certain qualitative tests such as the *lake test* for the confirmation of Al³⁺ ions are based upon adsorption i.e., Al(OH)₃ has the capacity to adsorb the colour of blue litmus from the solution.

9. Production of high vacuum. The adsorption of air in liquid air helps to create a high vacuum in a vessel. This process is used in high vacuum instruments

as Dewar flask for storage of liquid air or liquid hydrogen. The remaining traces of air can be adsorbed by charcoal from the vessel evacuated by a vacuum pump to give a very high vacuum.

10. Separation of inert gases. Due to the difference in degree of adsorption of gases by charcoal, a mixture of noble gases can be separated by adsorption on coconut charcoal at different temperatures.

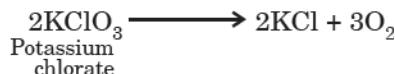
11. In froth floatation process. A low grade sulphide ore is concentrated by separating it from silica and other earthly matter by adsorption using pine oil and frothing agent. This has been discussed in Unit 6.

12. In curing diseases. A number of drugs are used to kill the germs by getting adsorbed on them.

13. Chromatographic analysis. The chromatographic technique for purification used in analytical and industrial fields is based on the phenomenon of adsorption.

CATALYSIS

There are many substances which increase the speed of reactions without being used up in the reaction. For example, you must have learnt that when potassium chlorate, (KClO_3) is heated strongly at 653–873 K, it decomposes very slowly as



However, when a little of manganese dioxide (MnO_2) is added, the decomposition occurs considerably at lower temperature range of 473–633 K and also at much faster rate. It is interesting to note that the added manganese dioxide remains unchanged with respect to its mass and composition. In a similar way, the rates of a number of chemical reactions can be increased by the presence of a foreign substance. Berzelius (in 1835) was the first scientist who made systematic study of the effect of various foreign substances on the rates of chemical reactions. He suggested the term **catalyst** for such substances. Thus,

a substance which alters the rate of a chemical reaction without itself undergoing any change in mass and chemical composition at the end of the reaction is called a **catalyst**.

The phenomenon of increasing the rate of reaction by the use of catalyst is called **catalysis**. The catalysts themselves remain chemically and quantitatively unchanged after the reaction. Since catalysts are not consumed in the reaction, very small non-stoichiometric quantities are generally required. The catalysts play very important role in a number of industrial processes. Catalysts are very essential for our existence. We cannot deny the fact that nature is the master designer and user of catalysts. Living cells contain thousands of different kinds of proteins called enzymes which act as catalysts. Every organism depends upon enzymes (catalysts) to sustain life.

POSITIVE AND NEGATIVE CATALYSIS

It may be noted that a catalyst may increase or decrease the speed of a reaction.

If a catalyst increases the rate of a chemical reaction, it is called a *positive catalyst* and the phenomenon is called **positive catalysis**.

On the other hand, if a catalyst decreases (retards) the speed of a reaction, it is called a *negative catalyst* and the phenomenon is called **negative catalysis**.

For example, oxidation of SO_2 to SO_3 in the presence of V_2O_5 (Contact process) is an example of positive catalysis. However, the decomposition of H_2O_2 in the presence of acetanilide or phosphoric acid gets retarded and is an example of negative catalysis. However, the term catalyst used as such implies positive catalyst.

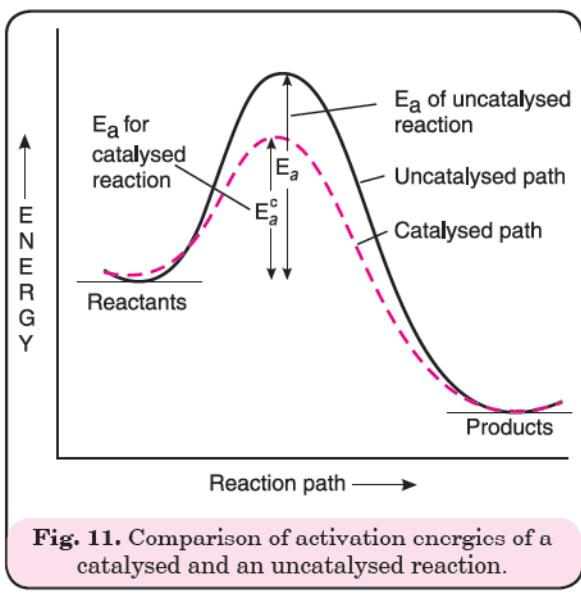


Fig. 11. Comparison of activation energies of a catalysed and an uncatalysed reaction.

REMEMBER

- It may be noted that:
- **positive catalyst** lowers the activation energy of the reaction and
 - **negative catalyst** raises the activation energy of the reaction.

Function of a Catalyst.

Although there is no universal principle behind the action of catalysts, but in general, a catalyst provides an entirely new path for the reaction in which the reactants are converted to the products quickly. We have learnt that a chemical reaction takes place by a reaction path, first converted to activated state and then finally to the products. It is believed that a catalyst forms a new activated complex of lower potential energy. This means that the catalyst provides a new pathway of lower activation energy. Consequently, the fraction of the total number of collisions possessing lower activation energy is increased and hence, the rate of reaction also increases. Fig. 11 gives an energy diagram which depicts the effect of a catalyst on the activation energy. The solid lines show the path for uncatalysed reaction and the dotted line shows the path adopted by catalysed reaction.

The following points should be kept in mind regarding the function of a catalyst :

(i) *A catalyst may undergo intermediate physical changes and it may even form temporary chemical bonds with the reactants but it is recovered unchanged in original form at the end of the reaction.*

(ii) *Although a catalyst speeds up the reaction, but it does not shift the position of equilibrium.* This is due to the fact that the presence of a catalyst reduces the height of barrier by providing an alternative path for the reaction and lowers the activation energy. However, the lowering in activation energy is to the same extent for the forward as well as for the backward reaction.

As a result, the increase in the rate of the forward and backward reactions is same and hence, the position of equilibrium remains unaltered. However, the equilibrium is attained earlier.

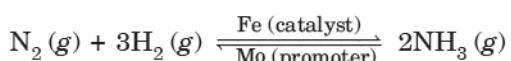
(iii) *Catalysts are highly specific in nature.* A catalyst which can catalyse one reaction may have no effect on another reaction even if that reaction is very similar.

(iv) *The catalyst does not change ΔE of the reaction.* This is clear that the addition of a catalyst does not change the energies of reactants (E_r) and products (E_p) so that ΔE ($E_p - E_r$) remains same.

(v) *The catalyst does not change thermodynamic parameters such as change in internal energy (ΔU), enthalpy (ΔH), entropy (ΔS) or Gibbs free energy (ΔG) for a reaction.*

Promoters and Poisons

Promoters are substances that enhance the activity of the catalyst. For example, in Haber's process for the manufacture of ammonia, molybdenum is used as promoter for iron, which acts as a catalyst.



The substances which decrease the activity of the catalyst are called **catalytic poisons**. For example, certain substances like CO, arsenic, etc. if present act as poisons because they lower the activity of the catalyst.

Classification of Catalysts

The catalysts may be of two main types :

1. **Homogeneous catalysts**
2. **Heterogeneous catalysts**

1. Homogeneous catalysts

When the catalyst is present in the same phase as the reactants, it is called **homogeneous catalyst** and the process is called **homogeneous catalysis**. Such type of reactions are called **homogeneous catalytic reactions**.

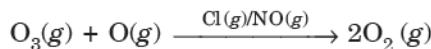
For example,

(i) In lead chamber process, SO_2 is oxidised to SO_3 in the presence of nitric oxide as catalyst :

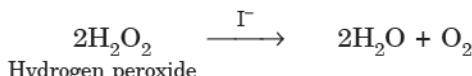


The reactants (sulphur dioxide and oxygen) and the catalyst (nitric oxide) all are in the same phase.

(ii) Catalytic decomposition of ozone in the presence of NO or Cl atoms as catalyst in the gas phase :



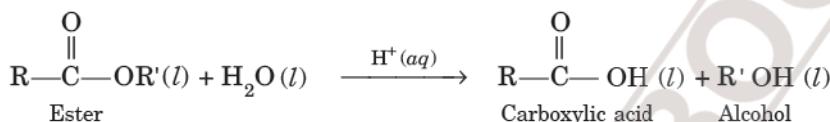
(iii) Decomposition of hydrogen peroxide in the presence of iodide ion as catalyst :



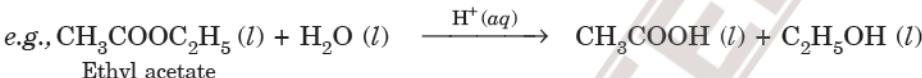
(iv) Carbon monoxide is oxidised by O_2 in the presence of nitric oxide (NO) as catalyst :



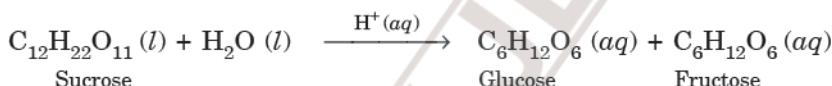
(v) Hydrolysis of an ester is catalysed by the presence of an acid :



where R and R' are alkyl groups.



(vi) Hydrolysis of sucrose is catalysed by the presence of dil. HCl or H_2SO_4 .



(vii) Preparation of diethyl ether from ethyl alcohol using conc. H_2SO_4 at 413 K.



In all these reactions, the reactants and the catalysts are in the same phase.

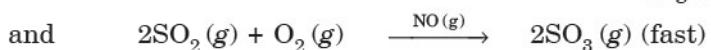
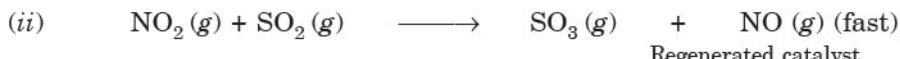
Mechanism of homogeneous catalytic reactions

These reactions can be explained on the basis of intermediate compound formation. According to this theory, the catalyst combines with one of the reactants to form an *intermediate*. Intermediate compound being *unstable* either decomposes or combines with the other reactant to form the product and the catalyst is regenerated. For example, the combination of SO_2 and O_2 to form SO_3 is a slow process. However, in the presence of NO (catalyst) the reaction becomes fast.



It is believed that in this reaction nitric oxide combines with one of the reactants to form intermediate compound (NO_2). This intermediate (NO_2) combines readily with SO_2 to form SO_3 and the catalyst NO is regenerated in the last step :





(a) Similarly, decomposition of ozone in the presence of NO takes place as :



(b) The decomposition of H_2O_2 takes place through the formation of intermediate IO^- (hypoiodite ion) as :



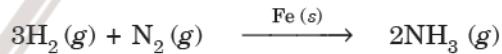
2. Heterogeneous catalysts

When the catalyst is in different phase than the reactants, it is called **heterogeneous catalyst** and the process is called **heterogeneous catalysis**. Such reactions are called **heterogeneous catalytic reactions**.

In heterogeneous catalysis, catalyst is generally a solid and the reactants are generally gases. Sometimes, liquid reactants are also used. This is also known as **surface catalysis** because the reaction starts at the surface of the solid catalyst. These catalysts have very large surface area of the order of 1 to 500 m^2 per gram for contact. It may be noted that many reactions which occur on a metal surface such as decomposition of HI on gold or the decomposition of N_2O on platinum are zero order reactions. This is because, the rate determining step occurs on the surface itself. Thus, despite an enormous surface area, once the reactant gas molecules cover the surface, the rate does not increase on increasing the reactant concentrations.

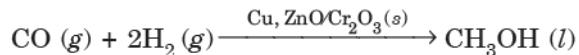
These are very important reactions in industries. Some other examples are:

(i) Manufacture of NH_3 from H_2 and N_2 by Haber's process using finely divided iron catalyst.

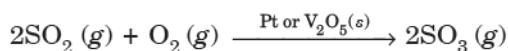


Here reactants are in the gaseous state while the catalyst is in the solid state.

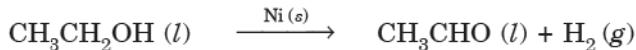
(ii) Methanol is prepared from CO and H_2 by using a mixture of copper, zinc oxide as catalyst and Cr_2O_3 as promoter :



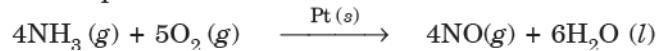
(iii) Manufacture of SO_3 from SO_2 in the Contact process using platinised asbestos or V_2O_5 as catalyst :



(iv) Dehydrogenation of ethanol by using nickel catalyst :



(v) Oxidation of ammonia into nitric oxide in the presence of platinum gauze in Ostwald's process :



(vi) Hydrogenation of vegetable oils in the presence of finely divided nickel as catalyst is also an example of heterogeneous catalytic reaction because one of the reactants is in liquid state and the other in gaseous state, while the catalyst is in the solid state.



REMEMBER

• Homogeneous catalysis:

Reactants and catalyst are in the same phase.

• Heterogeneous catalysis:

Reactants and catalyst are in different phases.

Learning Plus

➤ Ziegler-Natta catalyst

$[\text{Ti}-\text{R}_3\text{Al}$, where $\text{R} = -\text{CH}_3$ or C_2H_5] is a heterogeneous catalyst used in polymerisation of olefins.

➤ Wilkinson's catalyst

$[\text{RhCl}(\text{PPh}_3)]$ is a heterogeneous catalyst used in the hydrogenation of alkenes.

➤ Lindlar's catalyst

$(\text{Pd}-\text{BaSO}_4)$ is a heterogeneous catalyst. It is usually **poisoned by traces of quinoline**.

Mechanism of heterogeneous catalytic reactions

Adsorption Theory

The mechanism of heterogeneous catalysis was explained on the basis of a theory known as **adsorption theory**. According to this theory, the surface of the catalyst unlike the inner part of the bulk has free valencies which provide sites for chemical forces of attraction. The reactants in the gaseous state or in solution are adsorbed on the surface of the solid catalyst. As the reactant molecules are adsorbed, its bonds are weakened and the reaction can proceed quickly because the bonds are more quickly broken. For example, the most important step in the Haber process for the synthesis of ammonia is the adsorption of N_2 molecules on iron and the weakening of the strong $N\equiv N$ triple bond. Since the adsorption is an exothermic process, the heat of adsorption is utilised in weakening the bonds in the reactants and hence enhancing the rate of reaction. The increase in concentration of reactants on the surface increases the rate of reaction.

The catalytic action can also be explained in terms of intermediate compound formation, which has already been discussed.

Modern adsorption theory

The modern adsorption theory is a combination of old adsorption theory and intermediate compound formation. The heterogeneous catalysis is regarded as surface phenomenon in which the catalytic activity is localised on the surface of the catalyst. The heterogeneous catalysis is a surface phenomenon. It involves the following steps :

- (i) Diffusion of the reactants to the surface of the catalyst.
- (ii) Adsorption of the molecules of the reactant at the active sites.
- (iii) Occurrence of the chemical reactions on the surface of the catalyst through the formation of an intermediate.
- (iv) Desorption of product molecules from the surface and thereby making the surface available again for more reactions to occur.
- (v) Diffusion of products away from the surface of the catalyst. This is shown below :

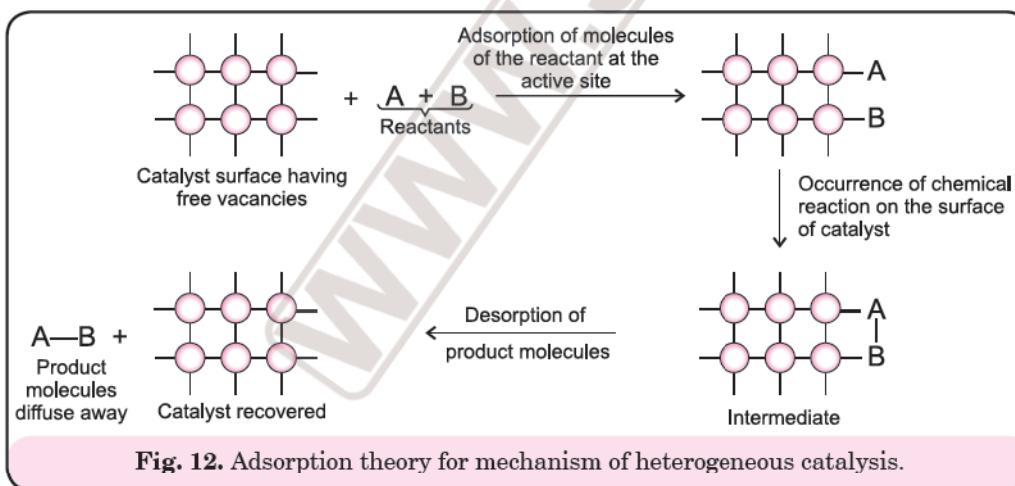


Fig. 12. Adsorption theory for mechanism of heterogeneous catalysis.

The role of heterogeneous catalysts can be explained in terms of **adsorption** of reactants on the surface of the catalyst. The adsorption helps the reaction in the following ways :

1. Adsorption increases the concentration of reactants on the surface of the catalyst. Due to increased concentration of the reactants, the reactions proceed rapidly.

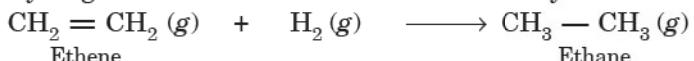
2. Adsorbed molecules get dissociated to form active species like free radicals which react faster than molecules.

3. The adsorbed molecules are not free to move about and, therefore, they collide with other molecules on the surface.

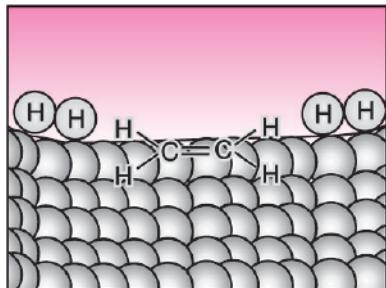
4. The heat of adsorption evolved acts as energy of activation for the reaction (chemisorption).

One of the most important examples of heterogeneous catalysis is the addition of H₂ to carbon-carbon double bonds (C = C) of organic compounds to form C—C bonds. This is known as **catalytic hydrogenation reaction** and is frequently used in petroleum, plastics and food industries. For example, conversion of vegetable oil into margarine.

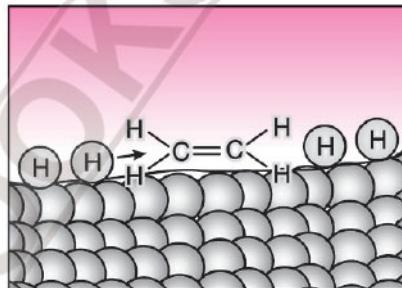
The simplest hydrogenation reaction is conversion of ethylene into ethane as:



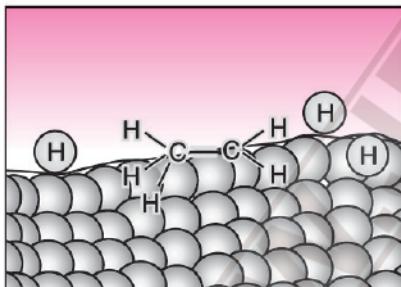
In the absence of catalyst, the reaction occurs very slowly. However, at high pressure of hydrogen and in the presence of finely divided nickel, palladium or platinum (as catalyst), the reaction becomes rapid even at ordinary temperature. The catalysed reaction is believed to proceed through the following consecutive steps as shown in Fig. 13.



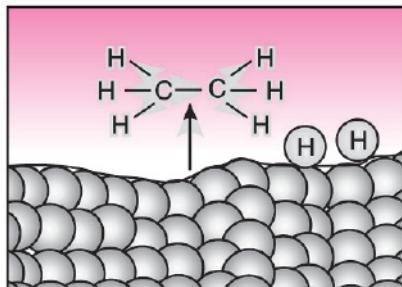
(a) H₂ and C₂H₄ adsord on Pt surface



(b) H₂ split up into 2H forming Pt-H bonds



(c) One H bonds with C_2H_4 to form C_2H_5

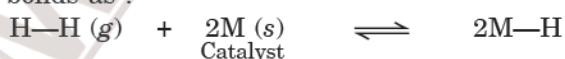


(d) Another C—H bond forms and C_2H_6 leaves the surface

Fig. 13.

(a) H₂ and ethene molecules approach the metal surface and get adsorbed to the metal surface.

(b) H_2 molecules get split up into H atoms which get chemically bound to the platinum catalyst i.e., metal atoms forming M—H bonds as :



This step is the **rate determining** step in the overall process.

(c) The H atoms move over the surface of platinum metal and one of them combine with ethene molecule to form C_2H_5 which remain attached to the platinum surface.

(d) Finally another H atom moves over the surface and combines with C_2H_5 forming C_2H_6 molecule, which leaves the surface.

The reaction occurs as :



The above theories explain why the catalysts remain unchanged in mass and chemical composition after the reaction and is effective even in small quantities. However, the theories do not explain the action of catalytic promoters and catalytic poisons.

Important Features of solid catalysts

The solid catalysts may be metals, alloys, metal oxides or metal sulphides. The effectiveness of a catalyst depends upon the two important aspects — *activity* and *selectivity*.

(i) Activity of a catalyst

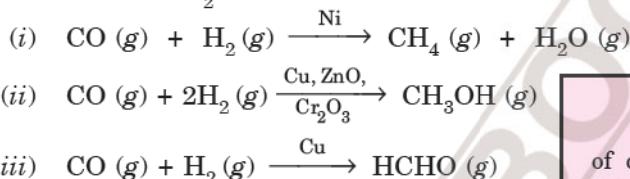
The ability of a catalyst to increase the rate of a chemical reaction is called **activity**. The activity of a catalyst depends upon the strength of chemisorption to a large extent. The reactant must adsorb reasonably strongly for the catalyst to be active but must not adsorb so strongly that they become immobilise and the other reactants do not get space on the catalyst surface for adsorption. It has been observed that for hydrogenation, the catalytic activity increases as we go from group 5 metals to group 11 metals with maximum activity shown by elements of group 7–9 the periodic table.

A catalyst may accelerate a reaction to as high as 10^{10} times. For example, the mixture of H_2 and O_2 can be stored for any period but in the presence of platinum, the reaction occurs with explosive violence.

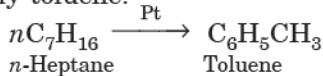


(ii) Selectivity of a catalyst

The ability of the catalyst to direct a reaction to give a particular product is called **selectivity**. For example, different catalysts give different products for the reaction between CO and H_2 as shown below :

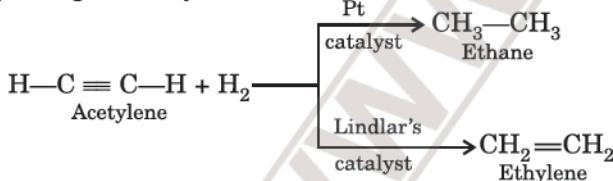


Similarly, *n*-heptane in the presence of Pt catalyst gives selectively toluene.



Propylene ($\text{CH}_3\text{CH}=\text{CH}_2$) reacts with O_2 in the presence of bismuth molybdate catalyst to selectively give acrolein ($\text{CH}_2=\text{CHCHO}$).

Similarly, acetylene on reaction with H_2 in the presence of Pt catalyst gives ethane while in the presence of Lindlar's catalyst (palladium and BaSO_4 poisoned with quinoline or sulphur) gives ethylene.



Thus, the action of catalyst is highly selective. A given catalyst can act as catalyst only in a particular reaction and not in all reactions. In other words, a substance which acts as a catalyst in one reaction may fail to catalyse other reaction. Thus, *catalyst is highly selective in nature*.

ENZYME CATALYSTS

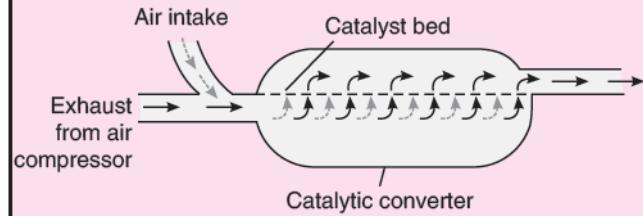
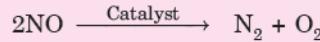
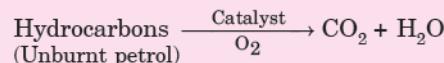
Large number of organic reactions are taking place in the body of animals and plants to maintain the life processes. These reactions are generally very slow and are remarkably catalysed by complex nitrogenous organic compounds known as **enzymes**. These are also called **biological catalysts** or **biochemical catalysts** and are produced by the living cells in plants and animals.

Thus, *enzymes are biological catalysts produced by living cells which catalyze the biochemical reactions in living organisms*.

Chemically all enzymes are proteins with molar mass ranging from 15,000 to 1,000,000 g/mol. Without enzymes, the living processes would be very slow

Catalytic converter for an Automobile

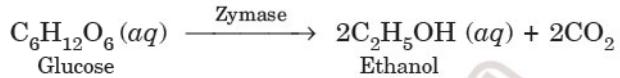
The catalytic converter in the exhaust systems of cars, which converts polluting exhaust gases into non-toxic gases contains a **heterogeneous catalyst**. Mixtures of transition metals and their oxides embedded in inert supports act as catalyst. When the gases are passed through the catalyst bed, carbon monoxide (CO) and unburnt petrol are oxidised to carbon dioxide and water while nitric oxide (NO) is reduced to N_2 as :



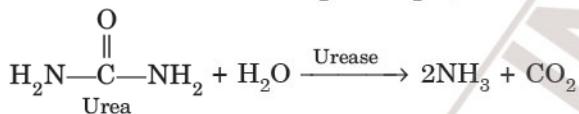
to sustain life. For example, without the presence of enzymes in our digestive tract, it would take about 50 years to digest a single meal. About 3000 enzymes have been identified. The enzymes differ from other types of catalysts in being highly selective and specific.

Some common examples of enzyme catalysis reactions are :

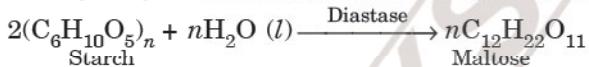
(i) Normal conversion of glucose into ethanol by **zymase** (enzyme) present in yeast.



(ii) Hydrolysis of urea (NH_2CONH_2) by **urease** (enzyme) present in soyabean.



(iii) Hydrolysis of starch into maltose by **diastase** (enzyme) present in malt.



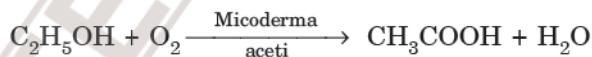
(iv) Conversion of maltose into glucose by **maltase** (enzyme) present in yeast.



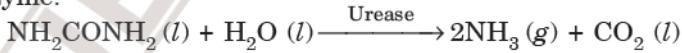
(v) Hydrolysis of sugar into glucose and fructose by **invertase** (enzyme) present in yeast.



(vi) Oxidation of alcohol to acetic acid by **mycoderma aceti** present in old vinegar.



(vii) Decomposition of urea into ammonia and carbon dioxide by **urease** enzyme.



(viii) In stomach, the **pepsin** enzyme converts proteins into peptides whereas in intestine, the **pancreatic trypsin** converts proteins into amino acids by hydrolysis.

(ix) Milk is converted into curd by the enzymatic reaction brought about by **lacto bacilli** enzyme present in curd. Some common examples of enzymes and enzymatic reactions are given in Table 1.

R U Curious...



Food in our body is digested quickly.

The digestion of food in our body takes place through reactions catalysed by enzymes present in our body. These biochemical reactions are highly efficient and specific. These enzymes speed up the rate of reaction by factors as high as 10^{20} . Moreover, extremely small quantities of enzyme catalysts are required. Thus, digestion of food is very fast. Without the presence of enzyme in our digestive system, it would take about 50 years to digest a single meal.

Table 1. Some common enzymatic reactions.

| Enzyme | Source | Enzymatic reaction | |
|------------------------|---------------|--------------------|-------------------------------------|
| Invertase | Yeast | Sucrose | → Glucose + Fructose |
| Diastase | Malt | Starch | → Maltose |
| Maltase | Yeast | Maltose | → Glucose + Glucose |
| Zymase | Yeast | Glucose | → Ethyl alcohol + CO ₂ |
| Urease | Soyabean | Urea | → CO ₂ + NH ₃ |
| <i>Mycoderma aceti</i> | Old vinegar | Ethyl alcohol | → Acetic acid |
| Pepsin | Stomach | Proteins | → Amino acid |
| Lactase | Dairy product | Lactose | → Glucose + Galactose |
| Amylase | Starch | Starch | → <i>n</i> Glucose |
| <i>Lacto bacilli</i> | Curd | Milk | → Curd |

Characteristics of Enzyme Catalysts

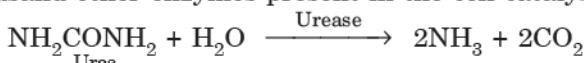
The important characteristics of enzyme catalysts are :

1. **High efficiency.** Enzyme catalysts increase the speed of reactions by 10^8 to 10^{20} times as compared to the uncatalysed reactions. The enzymes

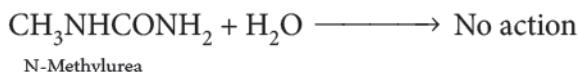
are highly efficient and one molecule of enzyme may transform one million molecules of the reactant per minute.

2. Extremely small quantities. Extremely small quantities of enzyme catalysts—as small as millionth of a mole—can increase the rate of reaction by factors of 10^3 to 10^6 . For example, the enzyme **renin** which is used for coagulation of milk to make cheese coagulates over a million times its own weight of milk protein.

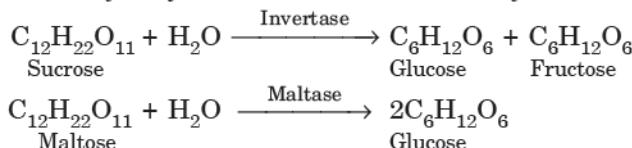
3. Specificity. The enzyme catalysts are highly specific in nature. Almost every biochemical reaction is controlled by its own specific enzymes. For example the enzyme, urease catalyses the hydrolysis of urea and none of the several thousand other enzymes present in the cell catalyse that reaction :



On the other hand, the same enzyme urease does not catalyse the hydrolysis of N-methylurea, which is similar in constitution to urea.



The enzyme **invertase** hydrolyses sucrose to glucose and fructose but does not hydrolyse maltose to glucose though both are hydrolytic reactions. But **maltase** catalyses the hydrolysis of maltose. No other enzyme can catalyse its hydrolysis.



4. Optimum temperature. The rate of an enzyme reaction becomes maximum at a definite temperature known as the **optimum temperature**. On either side of this temperature, the enzyme activity decreases. For example, the enzyme catalysts are active at moderate temperature 298–310 K and the human body temperature (310 K) is suited for enzyme catalysed reactions.

5. Optimum pH. The rate of an enzyme catalysed reaction is maximum at a particular pH called optimum pH. This is between pH values of 5–7.

6. Control of activity of enzymes. The action of enzyme catalytic reactions are controlled by various mechanisms and are inhibited by various organic and inorganic molecules.

7. Regulated activity. The activity of most enzyme catalysts is closely regulated.

8. Increasing activity in the presence of activators or coenzymes. Catalytic activity of enzymes is greatly enhanced by the presence of **activators** or **coenzymes**. Activators are metal ions (Na^+ , Mn^{2+} , Co^{2+} , Cu^{2+} etc.) which get weakly bonded to enzyme molecules and therefore, promote their catalytic action. In some cases, most active enzymes are associated with some non-protein components (vitamins) required for their activity. These are generally metal ions or small organic molecules and are collectively called **coenzymes**. The common metal ions are Zn, Mg, Mn, Fe, Cu, Co, Mo, K and Na.

9. Influence of inhibitors and poisons. Like ordinary catalysts, in some cases the enzyme activity can be reduced or inhibited by the presence of certain compounds known as **enzyme inhibitors** or **poisons**. These inhibitors or poisons interact with the active functional groups on the enzyme surface and often reduce or completely destroy the catalytic activity of the enzymes. The use of many drugs is related to their action as enzyme inhibitors in the body.

Mechanism of Enzyme Catalysed Reactions

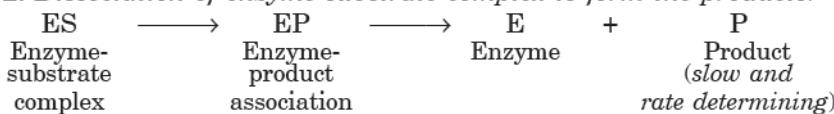
Biochemists are trying to explain the exact molecular basis of enzyme catalysis. The various steps involved in the enzyme catalysed reaction are given below:

Step. 1. Binding of the enzyme (E) to substrate (S) to form enzyme-substrate complex.



ES is called the enzyme-substrate complex.

Step. 2. Dissociation of enzyme-substrate complex to form the products.



The second step is slow and rate determining. The rate of enzyme catalysed reaction depends upon the concentration of ES. It changes from first order to zero order as the concentration of substrate is increased. The catalytic property of enzymes is present at certain specific regions on their surfaces. These are called active sites or *catalytic sites*. The active sites have characteristic shape and possess active groups such as $-\text{NH}_2$, $-\text{COOH}$, $-\text{OH}$, $-\text{SH}$, etc. These molecules of the reactants (substrate) which have complementary shapes fit suitably into these active sites. Specific binding accounts for the high specificity of these enzyme reactions. The specificity of fitting together of the substrate structure and the enzyme structure is explained on the basis of two models :

1. *Lock-and-key model.*
2. *Induced fit model.*

According to lock and key model, the substrate, the molecule on which the enzyme acts, fits into the slot as key fits into a lock. The shape of the active site of any given enzyme is such that only a specific substrate can fit into it, in the same way as one key can open a particular lock.

This is shown in Fig. 14.

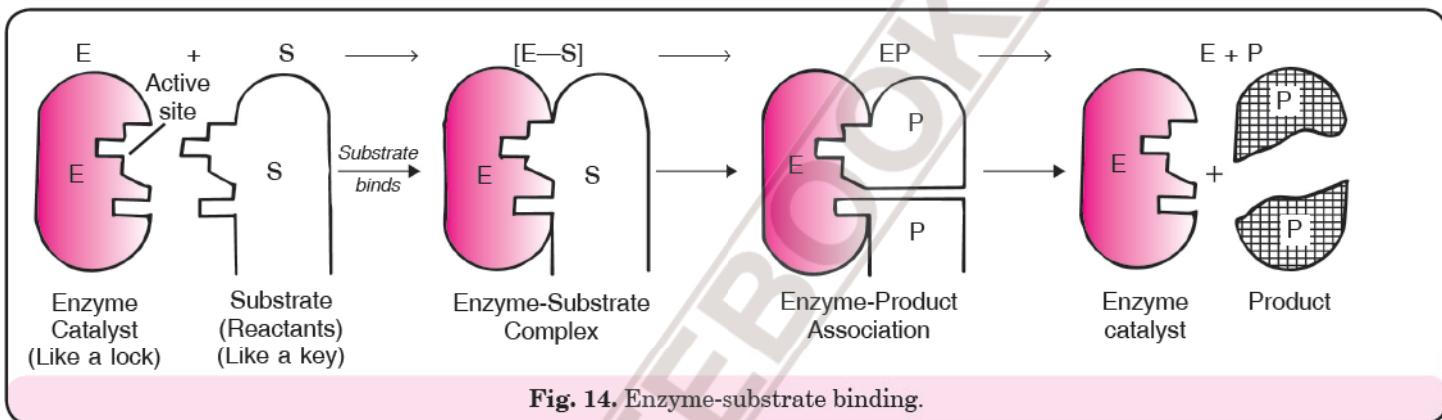


Fig. 14. Enzyme-substrate binding.

The binding site of the enzyme is such that it can bind only one substrate. The particular shape and the nature and location of the atoms at the binding site account for the **extraordinary specificity of the enzyme**.

Modern X-ray crystallographic and spectroscopic methods have shown that in many cases unlike an ordinary lock, the protein molecule (enzyme) slightly changes the shape when the substrate lands at the active site. The ability of the enzyme to undergo the correct distortion also determines whether the 'key' will fit or not. This refinement of the original lock-and-key model is known as **induced fit model**. According to this model, the substrate induces the active site to adopt a perfect fit rather than a rigidly shaped lock and key. Therefore, we can picture this model as **hand in a glove**, in which the glove (active site) does not attain its functional shape until the hand (substrate) moves into place.

Applications of Enzymes

1. Industrial applications. The enzymes are widely used in industrial processes. For example, enzymes are used

(i) in breweries for the manufacture of beer, wine, etc. by the fermentation of carbohydrates.

(ii) in food processing industries for preparing sweet syrup, etc.

(iii) in the production of cheese by coagulation of milk.

2. Enzyme deficiencies and prevention of diseases. The deficiencies of enzyme in living system cause many diseases. Some of these are given below :

(i) The deficiency of phenylalanine hydroxylase enzyme causes a congenital disease called **phenylketone urea**. This disease causes accumulation of compounds in the body which results into severe brain damage and retardation in children. This can be prevented by a diet with low phenylalanine content.

(ii) Deficiency of enzyme tyrosinase causes **albinism**.

These diseases can be prevented by the supply of enzymes through diet.

3. Curing diseases. Certain enzymes are also useful for treating heart diseases. An enzyme *streptokinase* is used to dissolve blood clot.

SHAPE SELECTIVE CATALYSIS BY ZEOLITES

The catalytic reaction which depends upon the pore structure of the catalyst and the size of the reactant and product molecules is called **shape selective catalysis**. Zeolites are good shape selective catalysts because of their honey comb like structures.

In recent years, one of the main advances in industrial chemistry have been the development of catalysts based on zeolites. These are microporous aluminosilicates of the general formula $M_{x/n} [(AlO_2)_x (SiO_2)y]m H_2O$. These are three dimensional networks of silicates in which some silicon atoms are replaced by aluminium atoms. These are porous and have cavities of molecular dimensions. The internal structure of a zeolite is a network of tunnels and cavities. Therefore, zeolites have an enormous surface area which is largely on the inside of the solid. The zeolites can permit the entry and exit of molecules of a certain size into the active regions within the holes. These are used in petrochemical industries for cracking of hydrocarbons and isomerization. The reactions in zeolites depend upon the size of the cavities (cages) and pores (tunnels) present in them. The most remarkable feature of zeolite catalysis is the **shape selectivity**. Therefore, the selectivity of catalyst depends on the pores structure. It has been observed that the pore size in zeolites generally varies between 260 pm and 740 pm. Depending upon the size of the molecules of reactants and products and the sizes of the pores of zeolites, reactions proceed in specific manner.

For example, zeolite catalyst known as ZSM-5 converts alcohols to gasoline. The alcohol is dehydrated in the cavities and the hydrocarbons are formed. The shape-selectivity in the reactions can be judged from the conversion of methanol and 1-heptanol to hydrocarbon mixtures.

| Product | Starting with CH_3OH (%) | Starting with $n-C_7H_{15}OH$ (%) |
|---------------------|-------------------------------|--------------------------------------|
| Methane | 1.0 | 0.0 |
| Ethane | 0.6 | 0.3 |
| <i>iso</i> -butane | 18.7 | 19.3 |
| <i>n</i> -butane | 5.6 | 11.0 |
| <i>iso</i> -pentane | 7.8 | 8.7 |
| Benzene | 1.7 | 3.4 |
| Toluene | 10.5 | 14.3 |
| Xylene | 17.2 | 11.6 |

The composition of the product mixture depends on the ability of the pores to accommodate linear and iso-alkanes as well as benzene derivatives.

Catalysts in industry

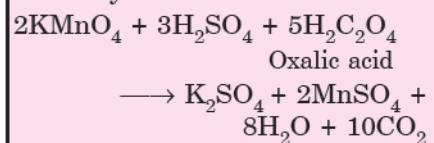
To increase the rates of reactions and to get maximum yields of products in minimum time, catalysts are used in the chemical industries. Some of the important technical catalytic processes are given below in Table 2.

Table 2. Some important industrial catalytic processes.

| Process | Catalyst | Conditions | Reaction |
|--|--|-------------------------------------|---|
| 1. Haber's process for the manufacture of ammonia | Finely divided iron (catalyst), molybdenum as promoter | 200 bar 723–773 K temperature | $N_2(g) + 3H_2(g) \xrightarrow[\text{200 bar, 723–773 K}]{\substack{\text{Fe (catalyst)} \\ \text{Mo (promoter)}}} 2NH_3(g)$ |
| 2. Ostwald's process for the manufacture of nitric acid | Platinised asbestos | 573 K | $4NH_3(g) + 5O_2(g) \xrightarrow{\text{Pt asbestos}} 4NO(g) + 6H_2O(g)$ $2NO(g) + O_2(g) \xrightarrow{573\text{ K}} 2NO_2(g)$ $4NO_2(g) + 2H_2O(l) + O_2(g) \longrightarrow 4HNO_3(aq)$ |
| 3. Contact process for the manufacture of sulphuric acid | Platinised asbestos or vanadium pentoxide (V_2O_5) | 673–723 K | $2SO_2(g) + O_2(g) \xrightarrow{V_2O_5} 2SO_3(g)$ $SO_3(g) + H_2SO_4(l) \xrightarrow{573–723\text{ K}} H_2S_2O_7(l)$ $H_2S_2O_7(l) + H_2O(l) \longrightarrow 2H_2SO_4(aq)$ |

Learning Plus

- **Catalytic poisons.** Certain substances like arsenic, CO, etc. if present lower the activity of the catalyst. These are called **catalytic poisons**.
- **Catalytic promoters.** Certain substances if present along with the catalyst increase the activity of the catalyst. These are called **catalytic promoters**. For example, molybdenum acts as a promoter for iron catalyst in the manufacture of ammonia by Haber's process.
- **Autocatalysis.** During a chemical reaction, if one of the products formed acts as a catalyst, the phenomenon is called autocatalysis. For example, during the titration of oxalic acid with $KMnO_4$ solution in the presence of dil. H_2SO_4 , the colour of $KMnO_4$ solution in the presence of dil. H_2SO_4 , the colour of $KMnO_4$ fades first slowly and then faster due to the formation of Mn^{2+} ions which act as auto catalyst.



add on

Conceptual Questions ■■■ 1

Q. 1. How is the adsorption of a gas related to its critical temperature ?

Ans. Higher is the critical temperature of a gas, greater is the ease of liquefaction of gas i.e., larger are the van der Waals forces of attraction. Therefore, greater is the adsorption.

Q. 2. Compare the heat of adsorption for physical and chemical adsorption.

Ans. The heat of adsorption for chemical adsorption is high (of the order of 200–400 kJ/mol) while the heat of adsorption for physical adsorption is low (of the order of 20–40 kJ/mol).

Q. 3. In case of chemisorption, why adsorption first increases and then decreases with temperature?

Ans. Chemisorption involves activation energy. The initial increase in chemisorption is due to the fact the heat supplied acts as activation energy and more and more molecules of adsorbate gain energy and possess energy greater than activation energy. Therefore, adsorption increases with increase in temperature. Further increase will increase the energy of the molecules absorbed and will increase the rate of desorption. Therefore, extent of adsorption decreases.

Q. 4. Give reason why a finely divided substance is more effective as an adsorbent ?

Ans. This is because a finely divided substance has larger surface area and, hence, more adsorption occurs.

Q. 5. A small amount of silica gel and a small amount of anhydrous calcium chloride are placed separately in two corners of a vessel containing water vapour. What phenomena will occur ?

Ans. Adsorption of water will occur on silica gel and absorption of water will occur on calcium chloride.

Q. 6. Which will be adsorbed more readily on the surface of charcoal and why : NH₃ or CO₂ ?

(A.I.S.B. 2004)

Ans. NH₃ has higher critical temperature than CO₂ and therefore, it is more easily liquefiable. Hence, NH₃ has greater intermolecular forces of attraction and will be adsorbed more readily.

Q. 7. What form Freundlich adsorption isotherm equation take at high pressure ?

Ans. $\frac{x}{m} = K_a$ i.e., it becomes independent of pressure at constant temperature.

Q. 8. How do the size of particles of adsorbent, pressure of gas and prevailing temperature influence the extent of adsorption ?

(A.I.S.B. 2004)

Ans. (i) Smaller the size of the particles of adsorbent, greater is the surface area and hence greater is the adsorption.
(ii) At constant temperature, adsorption first increases with increase of pressure and then attains equilibrium at high pressure and becomes constant.
(iii) In physical adsorption, it decreases with increase of temperature but in chemisorption, it first increases becomes maximum and then decreases.

Q. 9. Consider the adsorption isotherms and interpret the variation in the extent of adsorption (x/m) when

(a)(i) Temperature increases at constant pressure.

(ii) Pressure increases at constant temperature.

(b) Name the catalyst and the promoter used in Haber's process for manufacture of ammonia.

(C.B.S.E. Sample Paper 2007)

Ans. (a) (i) extent of adsorption (x/m) increases with decrease in temperature at constant pressure.

(ii) extent of adsorption (x/m) increases with increase in pressure at constant temperature.

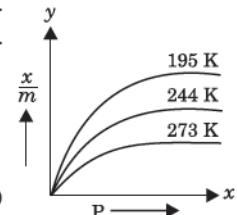
(b) In Haber's process :

Catalyst : finely divided iron

Promoter : molybdenum

Q. 10. Heat of adsorption is greater for chemisorption than physisorption. Why ?

(C.B.S.E. Sample Paper 2011)



Ans. Chemisorption has larger heat of adsorption than physisorption because chemical bonds are formed between adsorbent and adsorbate.

Q. 11. Why is silica gel used as a dehumidizer ?

Ans. Silica gel has stronger adsorption tendency for humidity (moisture of the air). Hence, it is used as a dehumidizer.

Q.12. Name the enzyme which converts :

(i) Starch into maltose (ii)Glucose into alcohol (iii)Sucrose into glucose and fructose. (Pb. S.B. 2014)

Ans. (i) Diastase (ii) Zymase (iii) Invertase.

Q.13. Write one similarity between physisorption and chemisorption.

(D.S.B. 2017, A.I.S.B. 2017)

Ans. Both are surface phenomena and increase with increase in surface area.

Q.14. Which enzyme is used to convert glucose into ethyl alcohol?

(H.P.S.B. 2017)

Ans. Zymase

COLLOIDAL STATE

Thomas Graham in 1861 observed that certain solutes such as starch, glue, gelatin etc. could not pass through the parchment membrane while the ordinary solutes such as sodium chloride, urea, sugar etc. can easily do so. Graham called the former solutes as *colloids* (Greek, *kolla* meaning glue) while the latter were called *crystalloids*. However, the above classification of solutes into crystalloids and colloids proved unsatisfactory because a particular substance would be crystalloid in one solvent and a colloidal in the other. For example in aqueous solution, NaCl is a crystalloid, while in benzene, it behaves as colloid. Similarly, soap is a typical colloid in water but it acts as a crystalloid in alcohol. Further studies of the behaviour of these solutes have shown that the nature of the substance whether colloid or crystalloid depends upon the particle size. When the size of the particles is between 10^{-9} m (1 nm) to 10^{-6} m (1000 nm), it behaves like a colloid and in case, it is less than this range, it gives the characteristics of crystalloid. Thus, **colloid is not a substance but it is a state of a substance which depends upon the molecular size.**

Three Types of Solutions

On the basis of the particle size of the substance, solutions may be divided into three types. These are :

1. *True solutions*
2. *Suspensions*
3. *Colloidal solutions.*

1. True solution is a homogeneous solution which contains small solute particles (molecules or ions) dispersed throughout a solvent. For example, the solution of sodium chloride in water. The **particle size is less than 1 nm**. The particles of a solute in a true solution are invisible even under microscope and its particles can pass through ordinary filter paper as well as through animal membrane.

2. Suspension is a heterogeneous mixture which contains small insoluble particles. The **particle size is more than 1000 nm**. For example, dirt particles in water. The particles of a suspension may not be visible to the naked eye but are visible under a microscope. The particles of a suspension can neither pass through an ordinary filter paper nor through animal membrane.

3. Colloidal solution is a heterogeneous solution which contains particles of intermediate size. For example, milk. The particles of a colloidal solution have **diameters between 1 to 1000 nm**. Such particles cannot be normally seen with a naked eye. However, light reflected by them can be seen under an ultramicroscope. The particles of a colloidal solution can pass through ordinary filter paper but not through animal membrane. In a colloid, the dispersed phase may consist of particles of a single macro molecule (such as synthetic polymer or protein) or an aggregate of many atoms, molecules or ions.

Colloidal particles have an enormous surface area per unit mass. For example, consider a cube having each side as 1 cm. It has total surface area of 6 cm^2 because it has six faces and each face has area of 1 cm^2 . Now, if it were divided equally into 10^{12} cubes, the cubes would be the size of large colloidal particles and have a total surface area of $60,000 \text{ cm}^2$ or 6 m^2 . This enormous area is responsible for some special properties of colloids which will be learnt in this unit.

Thus, **colloidal solutions are intermediate between true solutions and suspensions**. In other words, the size of dispersed particles in colloidal solutions is more than that of solute particles in a true solution and smaller than that of a suspension (Fig. 15).

REMEMBER

Colloidal state of matter is a state in which the size of particles is between 1 to 1000 nm and the particles can pass through filter paper but not through vegetable or animal membrane.

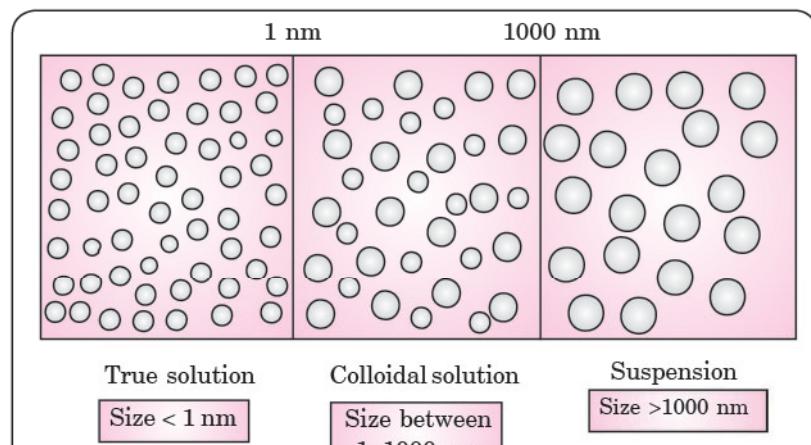


Fig. 15. Three types of solutions.

The size of different solutions are sometimes expressed in other units also as given below :

Size (diameter) of particles in different units

| True solutions | Colloids | Suspensions | Relation |
|---------------------|--------------------------------------|-----------------------|--------------------------------------|
| $< 10^{-9}$ m | 10^{-9} m to 10^{-6} m | $> 10^{-6}$ m | |
| < 1 nm | 1 nm – 1000 nm | > 1000 nm | $1 \text{ nm} = 10^{-9} \text{ m}$ |
| $< 10 \text{ \AA}$ | $10 \text{ \AA} - 10000 \text{ \AA}$ | $> 10000 \text{ \AA}$ | $1 \text{ \AA} = 10^{-10} \text{ m}$ |
| $< 1000 \text{ pm}$ | $1000 \text{ pm} - 10^6 \text{ pm}$ | $> 10^6 \text{ pm}$ | $1 \text{ pm} = 10^{-12} \text{ m}$ |

The important distinguishing features of the three types of solutions are as follows :

| Property | Suspension | Colloid Solution | True Solution |
|----------------------------------|---|---|--|
| 1. Nature | Heterogeneous | Heterogeneous | Homogeneous |
| 2. Particle size | > 1000 nm (or $> 10^{-6}$ m) | $1 \text{ nm} - 1000 \text{ nm}$ (or $10^{-9} - 10^{-6}$ m) | $< 1 \text{ nm}$ (or $< 10^{-9}$ m) |
| 3. Separation by | | | |
| (i) <i>Ordinary filtration</i> | Possible | Not possible | Not possible |
| (ii) Ultra-filtration | Possible | Possible | Not possible |
| 4. Setting of particles | Settle under gravity | Settle only on centrifugation | Do not settle |
| 5. Visibility | Particles visible to naked eye or under a microscope. | Scattering of light by the particles is observed under ultra-microscope | Particles are invisible |
| 6. Appearance | Opaque | Generally transparent | Transparent |
| 7. Tyndall effect | Shows | Shows | Does not show |
| 8. Diffusion of particles | Do not diffuse | Diffuses slowly | Diffuses rapidly |
| 9. Brownian movement | May show | Shows | Negligible |

Note : The terms Ultra-filtration, Tyndall effect and Brownian movement mentioned above will be discussed in the characteristics of colloids.

PHASES OF COLLOIDS AND THEIR CLASSIFICATION

We have learnt that a colloidal solution is of *heterogeneous nature*. It consists of **two phases** i.e., a dispersed phase and a dispersion medium.

(i) **Dispersed phase.** *It is the component present in small proportion and is just like a solute in a solution.* For example, in the colloidal solution of silver in water, the former acts as a dispersed phases (Fig. 16).

(ii) **Dispersion medium.** *It is generally component present in excess and is just like a solvent in a solution.* In the above example, water acts as a dispersion medium.

Thus, the particles of the dispersed phase are distributed in the dispersion medium. Out of solid, liquid and gas, each one can act as a dispersed phase and dispersion medium leading to eight types of colloidal systems (Table 3).

CLASSIFICATION OF COLLOIDS

The colloids are classified on the basis of the following criteria :

- A. *Physical state of dispersed phase and dispersion medium.*
- B. *Nature of interactions between dispersed phase and dispersion medium.*
- C. *Type of particles of the dispersed phase.*

A. Classification based on the Physical state of the Dispersed phase and Dispersion medium

Depending upon the physical state of dispersed phase and dispersion medium whether these are solids, liquids or gases, eight types of colloidal systems are possible. The examples of the various types of colloids and their typical names are given in Table 3 ahead. It may be noted that a gas mixed with another gas forms a homogeneous mixture and therefore, it is not a colloidal system.

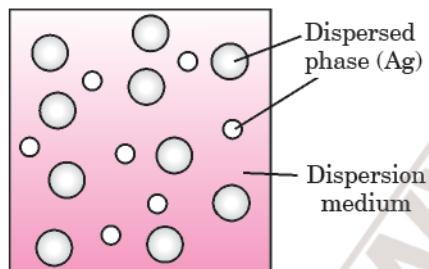


Fig. 16. A colloidal solution of silver in water.

Table 3. Types of colloidal systems.

| Dispersion phase | Dispersion medium | Type of colloid | Example |
|------------------|-------------------|-----------------|--|
| 1. Solid | Solid | Solid sol | Alloys, coloured glasses, gem stones, ruby glass |
| 2. Solid | Liquid | Sol | Paints, cell fluids, starch dispersed in water, gold sol |
| 3. Solid | Gas | Aerosol | Smoke, dust storm, haze |
| 4. Liquid | Solid | Gel | Jelly, butter, cheese, boot polish, curd |
| 5. Liquid | Liquid | Emulsion | Milk, hair cream, emulsified oils, medicines |
| 6. Liquid | Gas | Aerosol | Mist, fog, cloud, insecticide spray |
| 7. Gas | Solid | Solid sol | Pumice stone, foam rubber |
| 8. Gas | Liquid | Foam | Soap leather, froth, whipped cream, soda water |

It is clear from Table 3 that many common commercial products and natural objects are colloids. For example, whipped cream is a colloidal system (foam), a gas dispersed in a liquid. Out of the different types of colloids, the most common are **sols** (solids in liquids), **gels** (liquids in solids) and **emulsions** (liquids in liquids).

Depending upon the nature of the dispersion medium, colloidal solutions are sometimes given specific names. For example,

| Dispersion medium | Name of colloidal solution |
|-------------------|----------------------------|
| Water | Hydrosols or aquasol |
| Alcohol | Alcosols |
| Benzene | Benzosols |
| Air | Aerosols |

B. Classification based on Nature of Interaction between Dispersed Phase and Dispersion Medium

Depending upon the nature of interactions between dispersed phase and the dispersion medium, the colloidal solutions can be classified into two types as :

- (i) lyophilic and
- (ii) lyophobic sols.

(i) Lyophilic colloids

The colloidal solutions in which the particles of the dispersed phase have a great affinity (or love) for the dispersion medium, are called **lyophilic colloids**. The word 'lyophilic' means liquid loving. These solutions are easily formed and the lyophilic colloids are **reversible in nature**. The reversible nature of the sols is an important characteristic of lyophilic sols. This means that if the dispersion medium is separated from the dispersed phase (say by evaporation), the sol can be again formed by simply remixing it with the dispersion medium. These sols are quite stable and cannot be easily coagulated. In case water acts as the dispersion medium, the lyophilic colloid.

The common examples of lyophilic colloids are *gum, gelatin, starch, proteins, rubber, etc.*

(ii) Lyophobic colloids

The colloidal solutions in which there is no affinity (or love rather they have hatred) between particles of the dispersed phase and the dispersion medium are called **lyophobic colloids**. Such solutions are formed with difficulty. These sols are readily precipitated (or coagulated) on the addition of small amounts of electrolytes, by heating or by shaking. Therefore, these are not stable. Further, once precipitated, they do not form the colloidal sol by simple addition of dispersion medium. Hence, these are **irreversible in nature**.

Competition Plus

Nanomaterials are the materials having at least one dimension less than 100 nm. For detail, refer **Competition File, (Page 65)**.

The word '*lyophilic*' means liquid loving.

The word '*lyophobic*' means liquid hating.

These sols need some stabilising agents for their preservation. In case, the dispersion medium is water, the lyophobic sol is called **hydrophobic colloid**. For example, the solutions of metals like Ag and Au, hydroxides like Al(OH)_3 , Fe(OH)_3 , metal sulphides like As_2S_3 , etc.

Differences between Lyophilic and Lyophobic Colloids

The main differences between lyophilic and lyophobic colloids are summed below :

Table 4. Distinction between lyophilic and lyophobic colloids.

| Property | Lyophilic colloids | Lyophobic colloids |
|--------------------------------------|--|---|
| 1. Ease of preparation | These are easily formed by direct mixing. | These are formed only by special methods. |
| 2. Particles nature | The particles of colloids are true molecules and are big size. | The particles are aggregates of many molecules. |
| 3. Visibility | The particles are not easily visible even under ultramicroscope. | The particles are easily detected under ultramicroscope. |
| 4. Stability | These are very stable. | These are unstable and require traces of stabilizers. |
| 5. Action of electrolytes | They are not easily precipitated by small amount of electrolytes. Very large quantities of electrolytes are required to cause coagulation. | They are easily precipitated by the addition of small amount of suitable electrolytes. |
| 6. Reversible or irreversible nature | These are reversible in nature i.e., once precipitated can reform the colloidal sol by simply remixing with the dispersion medium. | These are irreversible in nature i.e., once precipitated cannot form the colloidal sol by simple addition of the dispersion medium. |
| 7. Charge on particles | The particles do not carry any charge. The particles may migrate in any direction or even not under the influence of an electric field. | The particles move in a specific direction i.e., either towards anode or cathode depending upon their charge. |
| 8. Hydration | The particles of colloids are heavily hydrated due to the attraction for the solvent. | The particles of colloids are not appreciably hydrated due to the hatred for the solvent. |
| 9. Viscosity | The viscosity of the sols is much higher than that of the dispersion medium. | The viscosity is nearly the same as that of the dispersion medium. |
| 10. Surface tension | The surface tension is usually lower than that of the dispersion medium. | The surface tension is almost the same as that of the dispersion medium. |
| 11. Tyndall effect | They do not show Tyndall effect. | They show Tyndall effect. |

C. Classification Based on type of particles of dispersed phase

Depending upon the type of the particles of the dispersed phase, the colloids are classified as :

- (i) **Multimolecular colloids**
- (ii) **Macromolecular colloids**
- (iii) **Associated colloids.**
- (i) **Multimolecular colloids**

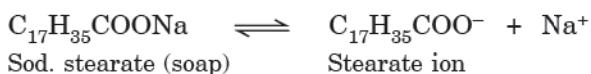
When on dissolution, atoms or smaller molecules of substances (having diameter less than 1 nm) aggregate together to form particles of colloidal dimensions, the particles thus formed are called **multimolecular colloids**. Therefore, in these sols the dispersed phase consists of aggregates of atoms or molecules with molecular size less than 1 nm. For example, sols of gold atoms and sulphur (S_8) molecules. In these colloids, the particles are held together by van der Waals forces.

(ii) Macromolecular colloids

These are the substances having big size molecules (called macro molecules) which on dissolution form solution in which the dispersed phase particles have size in the colloidal range. Such substances are called **macromolecular colloids**. These macromolecules forming the dispersed phase are generally polymers having very high molecular masses. Naturally occurring macro-molecules are starch, cellulose, proteins, enzymes, gelatin, etc. Artificial macro-molecules are synthetic polymers such as nylon, polythene, plastics, polystyrene, etc. Since these macromolecules have large sizes comparable to those of colloidal particles, the solutions of such molecules are called **macromolecular colloidal solutions**. Their solutions are quite stable and resemble true solution in many respects. Thus, the common examples of macromolecular colloids are starch, cellulose, proteins, plastics, etc.

(iii) Associated colloids

These are the substances which when dissolved in a medium behave as normal electrolytes at low concentration but behave as colloidal particles at higher concentration due to the formation of aggregated particles. The aggregate particles thus formed are called **micelles**. For example, in aqueous solution, soap (sodium stearate) ionises as :



In concentrated solution, these ions get associated to form an aggregate of colloidal size.

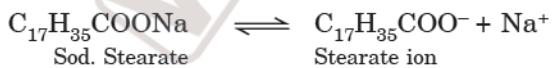
The colloidal behaviours of such substances is due to the formation of aggregates or clusters in solutions. Such aggregated particles are called micelles. Thus,

micelles are the cluster or aggregated particles formed by association of colloids in solution.

The common examples of micelles are soaps and detergents. The formation of micelles takes place above a particular temperature called **Kraft temperature (T_k)** and above a particular concentration called **critical micellization concentration (CMC)**. For example, CMC for soaps is about 10^{-4} – 10^{-3} mol L $^{-1}$. Different micelles have different values of CMC. On dilution, these colloids revert back to individual ions. These coloids have both lyophobic and lyophilic parts. The micelles may contain about 100 molecules or more.

Mechanism of Micelle Formation

Micelles are generally formed by the aggregation of several ions or molecules with lyophobic as well as lyophilic parts. For example, sodium stearate ($\text{C}_{17}\text{H}_{35}\text{COONa}$) is a typical example of such type of molecule. The micelle may contain as many as 100 molecules or more. When sodium stearate is dissolved in water, it gives Na^+ and $\text{C}_{17}\text{H}_{35}\text{COO}^-$ ions.



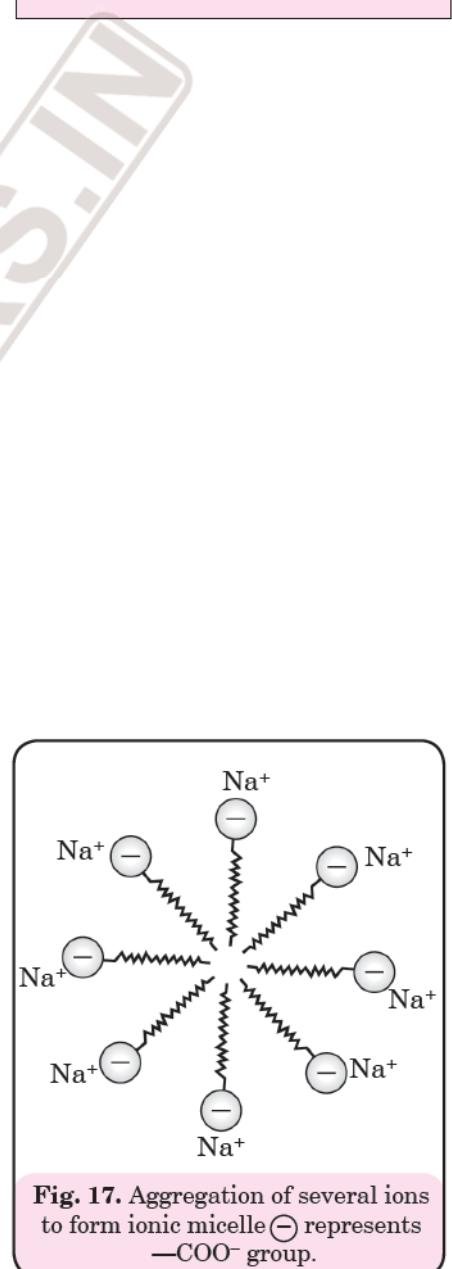
The stearate ions associate to form **ionic micelles** of colloidal size (Fig. 17). The stearate ion, $\text{C}_{17}\text{H}_{35}\text{COO}^-$ consists of two parts :

(i) a non-polar part which consists of long chain hydrocarbon part. It is called *non-polar 'tail'*. This part is insoluble in water but soluble in oil or grease. It is also called **water repelling or hydrophobic part**.

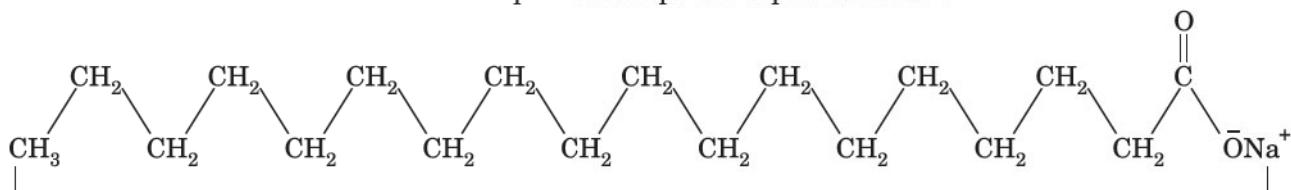
(ii) a polar group which consists of carboxylate ion, COO^- . It is called *polar-ionic head*. It is soluble in water and insoluble in oil or grease. It is **water attracting or hydrophilic part**.

Learning Plus

- Multimolecular colloids usually have lyophobic character.
- Macromolecular colloids usually have lyophilic character.

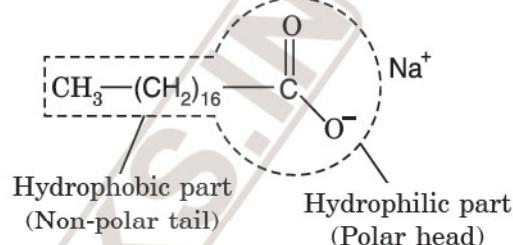


These two parts of soaps are represented as :

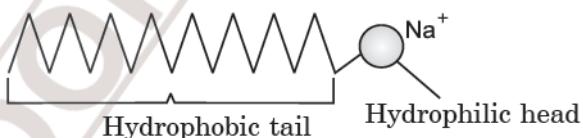


Sodium stearate ($C_{17}H_{35}COO^-Na^+$)

or simply as,



For simplicity, it may be represented as :



The stearate ions are therefore, present on the surface with their COO^- groups in water and the hydrocarbon tail staying away from it and remains at the surface. Inside water, these molecules have a unique orientation which keeps the hydrocarbon portion out of water. At critical micelle concentration, the anions are pulled into the bulk of the solution and form a cluster of molecules in which the hydrocarbon tails are in the interior of the cluster and ionic ends are at the surface of the cluster. This formation is called **micelle formation** and the aggregate thus formed is known as **ionic micelle** (as shown in Fig.17). These micelles may contain as many as upto 100 ions. When the concentration of the solution is below its CMC (10^{-3} mol L $^{-1}$), it behaves as normal electrolyte. But above this concentration, it is aggregated to behave as micelles.

Some other examples of micelles are :

(i) Sodium palmitate $(C_{15}H_{31}COONa)$

(ii) Cetyl trimethyl ammonium bromide $CH_3(CH_2)_{15}(CH_3)_3N^+Br^-$

(iii) Sodium lauryl sulphate $[CH_3(CH_2)_{11}SO_3^-Na^+]$

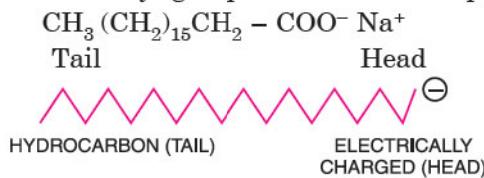
Similarly in case of detergents, e.g., sodium lauryl sulphate, $CH_3(CH_2)_{11}OSO_3^-Na^+$, the polar group is SO_4^{2-} along with the long hydrocarbon chain. Therefore, the mechanism of micelle formation is same as that of soaps.

Differences between multimolecular colloids, macromolecular colloids and associated colloids.

| Multimolecular colloids | Macromolecular colloids | Associated colloids |
|---|--|--|
| 1. They consist of aggregates of atoms or molecules which generally have diameter less than 1 nm. e.g., sols of gold, sulphur, etc. | They consist of large size molecules (generally polymers) like rubber, nylon, starch, proteins, etc. | They consist of aggregation of a large number of ions which behave as colloidal size particles at higher concentrations e.g., soap sols. |
| 2. The atoms or molecules are held by weak van der Waals forces. | The molecules are flexible and can take any shape. | They behave as normal electrolytes at low concentrations and behave as colloidal only at high concentrations. |
| 3. Their molecular masses are not very high. | They have high molecular masses. | Their molecular masses are generally high. |
| 3. They usually have lyophobic character. | They usually have lyophilic character. | Their molecules contain both lyophilic and lyophobic groups. |

Cleansing action of soap

The cleansing action of soap is due to its tendency to act as micelle and form emulsions. A soap, for example, sodium stearate is composed of long chain of alkyl group called *tail* and a polar part of COO^- ion called *head*.



This may be represented as the polar end which is water soluble and the non-polar end which is soluble in organic solvents and oil.

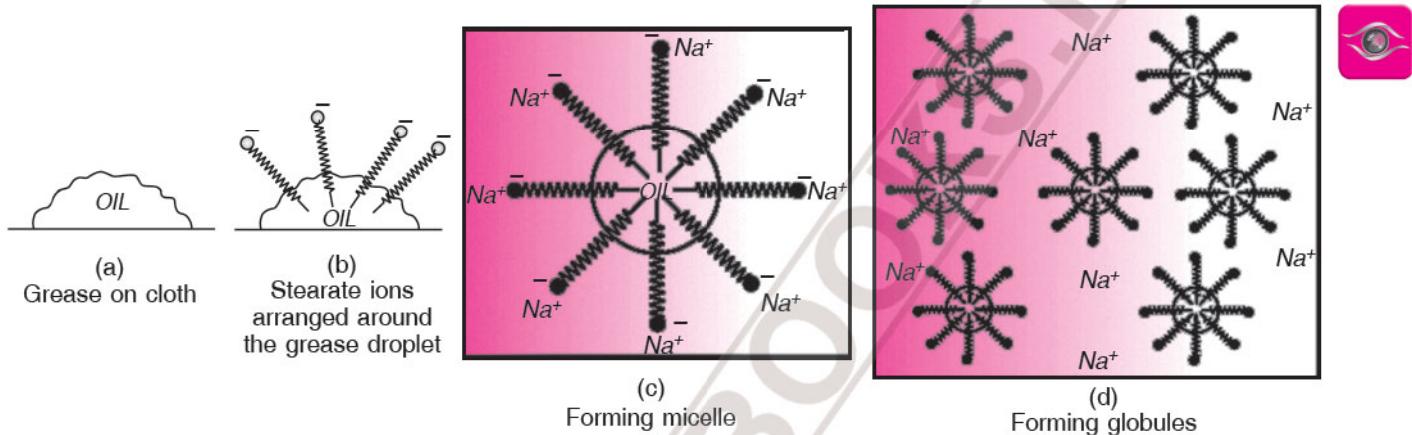


Fig. 18. Cleansing action of soap.

Ordinarily, the dirt in the cloth is due to the presence of dust particles in fat or grease which stick to the cloth. When the cloth is dipped in aqueous soap solution, the soap and the dirt come in contact with each other. The soap molecules form micelle around the oil droplet in such a way that the hydrophobic part of stearate ions is in the oil or grease droplet while the hydrophilic part projects out of the grease droplet like the bristles. In this manner, each oil droplet is surrounded by a number of negatively charged carboxylate ions (Fig. 18). Since similar charges repel each other, the oil droplets break up and form small droplets or globules. The negatively charged sheath around the globules prevents them from coming together and form aggregates. These small droplets get dispersed in water forming emulsion. The hand rubbing or the agitation due to the washing machine causes dispersion of the oil or grease throughout the soapy water. These are washed away with water alongwith dust particles.

GENERAL METHODS OF PREPARATION OF SOLS

Lyophilic and lyophobic colloidal solutions (or sols) are generally prepared by different types of methods. Some of the common methods are :

Preparation of Lyophilic Colloids

The lyophilic colloids have strong affinity between particles of dispersed phase and dispersion medium. Therefore, these colloidal solutions are readily formed by *simply mixing the dispersed phase and dispersion medium under ordinary conditions*. For example, the substances like gelatin, gum, starch, egg albumin etc. pass readily into water to give colloidal solution. They are reversible in nature because these can be precipitated and directly converted into colloidal state.

Preparation of Lyophobic Colloids

Lyophobic sols can be prepared by mainly two types of methods :

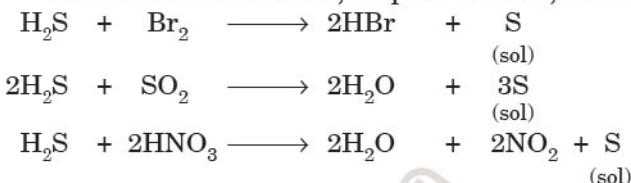
1. Condensation methods
2. Dispersion methods.

1. Condensation Methods

In these methods, smaller particles of dispersed phase are condensed suitably to be of colloidal size. This is done by the following methods :

(a) By chemical reactions.

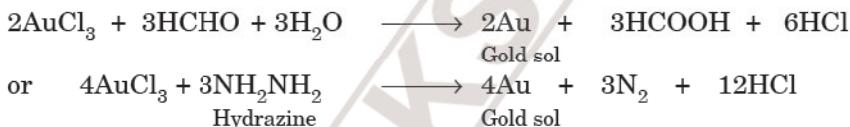
(i) Oxidation. A colloidal sol of sulphur is obtained by bubbling H_2S gas through the solution of bromine water, sulphur dioxide, nitric acid, etc.



(ii) Reduction. The colloidal solutions of metals are obtained by reduction of their compounds. For example, a solution of $AuCl_3$ is reduced with $SnCl_2$.



The reaction can also be carried out with formaldehyde, tannic acid or hydrazine.



The gold sol, thus prepared, has a purple colour and is called *purple of cassius*.

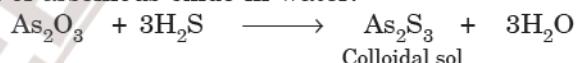
Colloidal sols of platinum, silver, etc. can also be prepared in a similar manner.



(iii) Hydrolysis. A colloidal solution of ferric hydroxide is prepared when a concentrated solution of ferric chloride is added drop wise to hot water.



(iv) Double decomposition. As_2S_3 sol is obtained by passing H_2S through dilute solution of arsenious oxide in water.



(b) By excessive cooling. A colloidal solution of ice in an organic solvent like ether or chloroform can be prepared by freezing a solution of water in the solvent. The molecules of water which can no longer be held in solution, separately combine to form particles of colloidal size.

(c) By exchange of solvent. Colloidal solution of certain substances such as sulphur, phosphorus which are soluble in alcohol but insoluble in water can be prepared by pouring their alcoholic solution in excess of water. For example, alcoholic solution of sulphur on pouring into water gives milky colloidal solution of sulphur.

(d) By change of physical state. Sols of substances like mercury and sulphur are prepared by passing their vapours through a cold water containing a suitable stabilizer such as ammonium salt or citrate.

2. Dispersion Methods

In these methods, larger particles of a substance (suspension) are broken into smaller particles. The following methods are employed:

(a) Mechanical dispersion. In this method, the substance is first ground to coarse particles. It is then mixed with the dispersion medium to get a suspension. The suspension is then grinded in a *colloidal mill* (Fig. 19). It consists of two metallic discs nearly touching each other and rotating in opposite directions at a very high speed (about 7000 revolutions per minute).

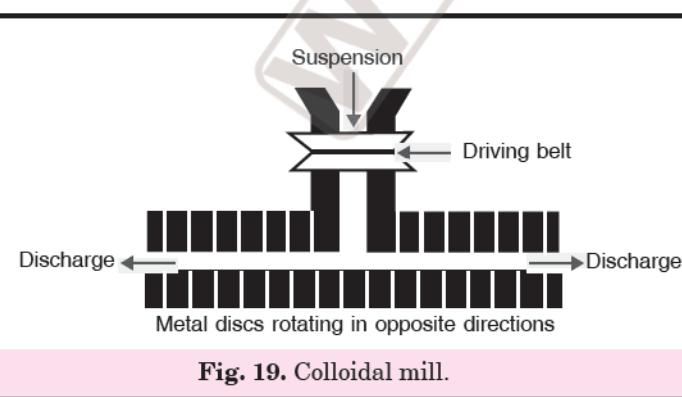


Fig. 19. Colloidal mill.

The space between the discs of the mill is so adjusted that coarse suspension is subjected to great shearing force giving rise to particles of colloidal size. Colloidal solutions of black ink, paints, varnishes, dyes, etc. are obtained by this method.

(b) **By electrical dispersion or Bredig's arc method.** This method is used to prepare *sols of metals such as platinum, silver, copper or gold*.

The metal whose sol is to be prepared is made as two electrodes immersed in dispersion medium such as water (Fig. 20). The dispersion medium is kept cooled by surrounding it with a freezing mixture. An electric arc is struck between the electrodes. The tremendous heat generated by the arc vapourises the metals which are condensed immediately in the liquid to give colloidal solution. *The colloidal solution prepared is stabilised by adding a small amount of KOH to it.*

(c) **By peptization.** *The process of converting a freshly prepared precipitate into colloidal form by the addition of a suitable electrolyte is called peptization.*

The electrolytes used for the purpose are called *peptising agents*.

Cause of peptization. When an electrolyte is added to a freshly prepared precipitate, the suitable ions from the added electrolyte are adsorbed by the particles of the precipitate. The charged particles repel one another and form colloidal solution. For example, treating a precipitate of iron (III) oxide with a small amount of FeCl_3 solution, gives a reddish brown coloured colloidal solution. In this case, Fe^{3+} ions from ferric chloride are adsorbed by Fe(OH)_3 precipitate :

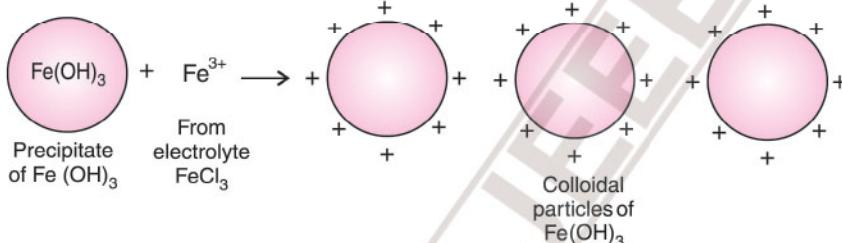
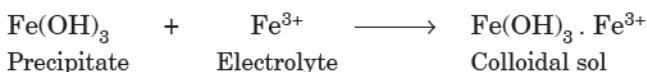


Fig. 21. Preparation of colloidal sol by peptisation.

Similarly, a precipitate of silver chloride can be peptised by shaking with a dilute solution of silver nitrate to give a colloidal solution of silver chloride.



PURIFICATION OF COLLOIDAL SOLUTIONS

The colloidal solutions prepared by the above methods usually contain impurities especially electrolytes which can destabilize the sols. These impurities must be eliminated to make the colloidal solutions stable. The following methods are commonly used for the purification of colloidal solutions.

1. Dialysis

The process of separating the particles of colloids from those of crystalloids by means of diffusion through a suitable membrane is called dialysis.

Its principle is based upon the fact that *colloidal particles cannot pass through a parchment or cellophane membrane while the ions of the electrolyte can pass through it*. The colloidal solution is taken in a bag made of cellophane or parchment. The bag is suspended in fresh water. The impurities slowly

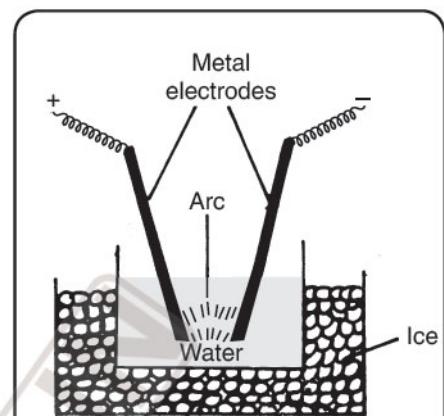


Fig. 20. Bredig's arc method.

diffuse out of the bag leaving behind pure colloidal solution Fig. 22. The distilled water is changed frequently to avoid accumulation of the crystalloids otherwise they may start diffusing back into the bag. Dialysis can be used for removing HCl from the ferric hydroxide sol.

Electrodialysis. The ordinary process of dialysis is slow. To increase the process of purification, the dialysis is carried out by applying electric field. This process is called *electrodialysis* and is shown in Fig. 23.

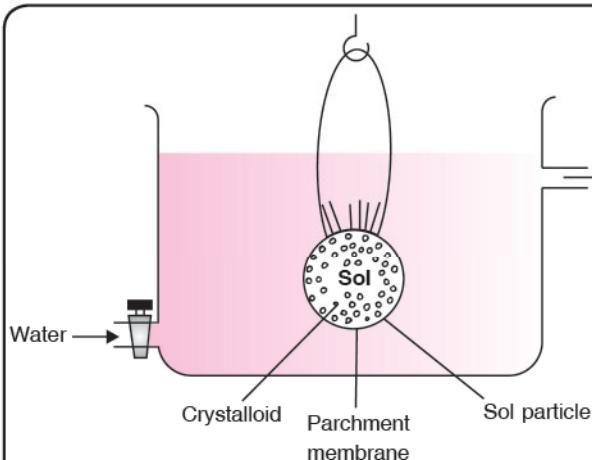


Fig. 22. Dialysis.

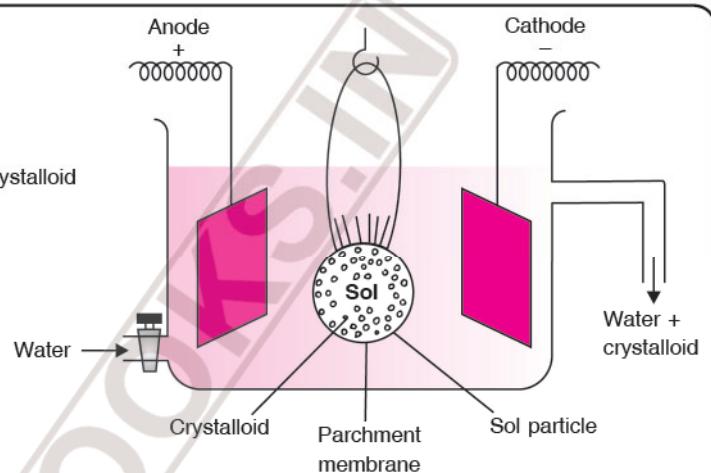


Fig. 23. Electrodialysis.

R U Curious...



Some patients have to undergo dialysis. How does it help?

► Kidneys in the human body act as dialysers to purify blood which is of colloidal nature. The most important application of dialysis process is the *artificial kidney machine* used for the purification of blood of the patients whose kidneys have failed to work. The artificial kidney machine (called **dialyser**) work on the principle of dialysis. It takes blood from the artery and the dialysis membrane in the machine allows small particles of excess ions and waste products to pass through while it does not allow the colloidal size particles such as haemoglobin to pass through. Therefore, blood of the patient is purified and after purification it is sent back to veins.

2. Ultra-filtration

It is the process of removing the impurities from the colloidal solution by passing it through graded filter papers called ultra-filter papers.

These filter papers are permeable to all substances except colloidal particles. Colloidal particles can pass through ordinary filter paper because the size of the pores is too large. However, the size of the pores of filter paper can be reduced by impregnating them with **colloidion** or **gelatin** solution to stop the flow of colloidal particles. The colloidion solution generally used is 4% solution of nitrocellulose in a mixture of alcohol and ether. An ultra-filter paper may be prepared by soaking the filter paper in a colloidion solution, hardening by dipping in formaldehyde solution and then finally drying it. A series of graded ultra-filter papers may be obtained by using the impregnating solutions of different concentrations. With these ultra-filter papers impurities of different sizes can be effectively removed. In this method, sol is poured over the ultrafilters which allow solution of impurities to pass through but retain the colloidal particles. The colloidal particles left on the ultra-filter paper are then stirred with fresh dispersion medium (solvent) to get a pure colloidal solution. This is a slow process and to speed up the process, pressure or suction is applied.

3. Ultra-centrifugation

In this method, the colloidal sol is taken in a tube which is placed in an ultra centrifuge. On rotation of the tube at high speeds, the colloidal particles settle down at the bottom of the tube and the impurities remain down in the solution called **centrifugate**.

The settled colloidal particles are mixed with an appropriate dispersion medium to regenerate the sol.

PROPERTIES OF COLLOIDAL SOLUTIONS

The main characteristic properties of colloidal solutions are discussed below :

1. Physical Properties

(a) **Heterogeneous character.** The colloidal solutions are heterogeneous in nature consisting of two phases : (i) *dispersed phase* and (ii) *dispersion medium*. Because of the small particle size, the colloidal solutions generally appear to be homogeneous to the naked eye but their heterogeneity can be confirmed by seeing under electron microscope.

(b) **Stable nature.** The colloidal solutions are quite stable. Their particles are in a state of motion and do not settle down at the bottom of the container. However, particles of certain colloidal sols, which have comparatively large size may settle down but very slowly.

(c) **Filtrability.** The colloidal particles can pass through ordinary filter papers because the size of the colloidal particles is lesser than the size of the pores of filter paper. However, they cannot pass through animal and vegetable membranes and ultrafilter papers. This forms the basis of separation of colloidal particles from those of crystalloids.

2. Colligative Properties

The colloidal particles being bigger aggregates have very high molecular masses so that the number of particles per litre of the sol is relatively very small than in a true solution. Therefore, they have very low colligative properties. As a result, the sols boil and freeze at almost the same temperature as the pure dispersion medium and lowering in vapour pressure is also negligible. However, *the osmotic pressure of colloidal solutions, though smaller than true solutions is the only colligative property which has been determined with a reasonable degree of accuracy*. It gives information regarding the number of particles present per kilogram of the dispersion medium and this can be used to determine the average molecular masses of colloidal particles.

3. Mechanical Properties

(a) **Brownian movement.** When colloidal solutions are viewed through a powerful ultramicroscope, the colloidal particles are seen to be in a state of continuous zig-zag motion. This motion was first observed by the British botanist, Robert Brown in 1827. He discovered that the pollen grains suspended in water do not remain at rest but move about continuously and randomly in all directions. Later on, it was observed that the colloidal particles also are moving at random in a zig-zag motion as shown in Fig. 24. This type of motion is called **Brownian movement** after the name of its discoverer, Robert Brown. The Brownian motion is independent of the nature of the colloid but depends on the size of the particles and viscosity of solution. Smaller the size and lesser the viscosity, faster is the motion.

Cause of Brownian movement. The Brownian movement has been explained to be due to the unbalanced bombardment of the particles by the molecules of the dispersion medium. The molecules of the dispersion medium are constantly colliding with the particles of the dispersed phase. It was stated by Wiener in 1863 that the impacts of the dispersion medium particles are unequal, thus, causing a zig-zag motion of the dispersed phase particles. When a molecule of dispersion medium collides with a colloidal particle, it is then displaced in one direction. Then another molecule strikes it, displacing it to another direction and so on. This process gives rise to a zig-zag motion. Thus, Brownian movement has a stirring effect which does not allow the particles to settle down and hence is responsible for the stability of the sols. However, if the size of the dispersed phase particles increases, then the chances of unequal bombardment decrease. *This can be confirmed by the fact that the suspensions do not show any such movement due to large molecular size.*

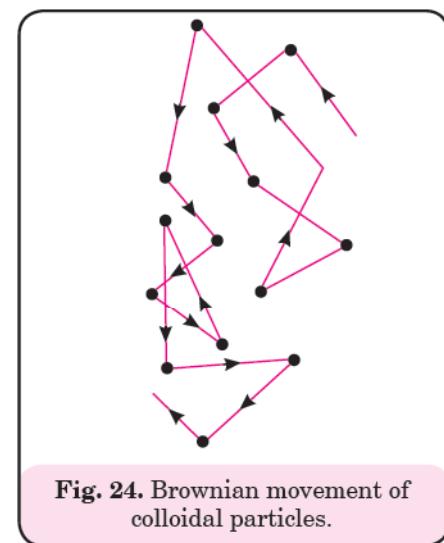


Fig. 24. Brownian movement of colloidal particles.

Thus, it may be noted that

(i) Brownian movement provides a direct demonstration of the ceaseless motion of molecules as postulated by kinetic theory.

(ii) The Brownian movement explains the force of gravity acting on colloidal particles. This helps in providing stability to colloidal sols by not allowing them to settle down.

(iii) It has also helped in the determination of Avogadro's number.

(b) **Diffusion.** The sol particles diffuse from higher concentration to lower concentration region. However, due to bigger size, they diffuse at a lesser speed.

(c) **Sedimentation.** The colloidal particles settle down under the influence of gravity at a very slow rate. This phenomenon is called sedimentation and is used to determine the molecular mass of macromolecules.

4. Optical Properties

(a) Tyndall effect

When a strong beam of light is passed through a true solution placed in a beaker, in a dark room, the path of the light does not become visible. However, if the light is passed through a sol, placed in the same room, the path of the light becomes visible when viewed from a direction at right angle to that of the incident beam. The colloidal solutions appear reasonably clear or translucent by the transmitted light but they show a mild to strong opalescence when viewed at right angles to the passage of light i.e., the path of beam gets illuminated by a bluish light.

This phenomenon was first observed by Faraday and later studied in detail by Tyndall and therefore, it is called **Tyndall effect**. *The cause of Tyndall effect is the scattering of light by the colloidal particles i.e., these particles scatter light in all directions in space. The scattering of light illuminates the path of beam in the colloidal dispersion. The particles in true solution are too small in size to cause any scattering i.e., the Tyndall effect is not observed in true solutions. Thus,*

the phenomenon of scattering of light by colloidal particles as a result of which the path of the beam becomes visible is called Tyndall effect.

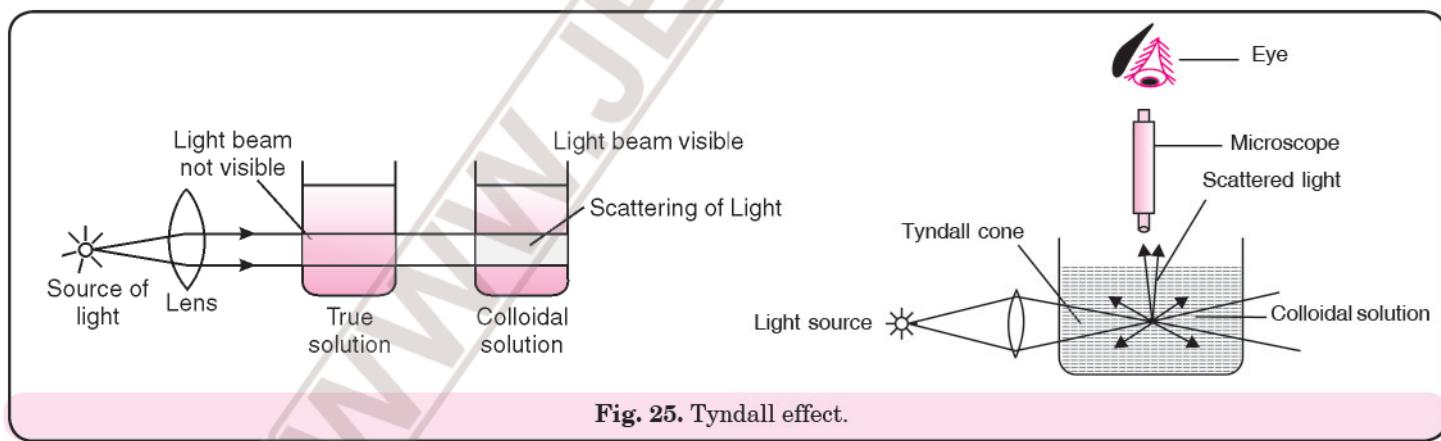


Fig. 25. Tyndall effect.

The illuminated path of the beam is called **Tyndall cone**.

The Tyndall effect confirms the *heterogeneous nature of the colloidal solutions*.

The Tyndall effect can be observed due to scattering of dust particles, when a beam of sunlight enters a dark room through a slit. You must have noticed during the projection of picture in the cinema hall due to scattering of light by dust and smoke particles present there.

Tyndall effect is observed only when the following two conditions are satisfied :

(i) The diameter of the dispersed phase particles is not much smaller than the wavelength of light used.

(ii) The refractive indices of the dispersed phase and the dispersion medium differ largely in magnitude.

Importance of Tyndall effect

The Tyndall effect has been used to devise an instrument called *ultramicroscope* which was designed by Zsigmondy in 1913. In this instrument, an intense beam of light is focussed on the colloidal solution contained in a glass vessel. The focus of light is then viewed with a microscope at right angles to the beam. It is observed that individual colloidal particles appear as spots of bright light against a dark background. It may be noted that ultramicroscope does not make the actual colloidal particles visible but only the light scattered by the colloidal particles can be seen through a microscope. Thus, ultramicroscope does not provide any information about the size and shape of colloidal particles.

(b) Colour

The colour of colloidal solutions depends on the wavelength of the light scattered by the dispersed particles. The wavelength further depends on the size and nature of the particles. It has been observed that the colour of colloidal solutions also changes with the manner in which the observer receives the light. For example, a mixture of milk and water appears blue when viewed by the reflected light but if transmitted light is viewed it is red. Similarly, gold sol is red in colour when the particles are fine but as the size of the particles increases, its colour changes to purple, then blue and finally golden.

5. Electrical properties

The particles of the colloidal solutions possess electrical charge, positive or negative. The presence of charge is responsible for the stability of these solutions. It may be noted that only the sol particles carry some charge while the dispersion medium has no charge. For example, the colloidal solutions of gold, arsenious sulphide (As_2S_3) are negatively charged while those of Fe(OH)_3 and Al(OH)_3 have positive charge. In the case of silver chloride sol, the particles may either be positively or negatively charged.

Origin of charge

Various views have been put forward regarding the origin of charge on the colloidal particles.

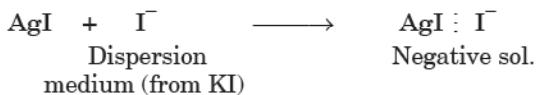
(i) **Due to frictional electrification.** It is believed that the frictional electrification due to the rubbing of the dispersed phase particles with that of dispersion medium results in some charge on the colloidal particles. But the dispersion medium must also get some charge because of the friction. Since it does not carry any charge, the theory does not seem to be correct.

(ii) **Due to dissociation of the surface molecules.** Consider, for example, an aqueous solution of soap (sod. palmitate) which dissociates into ions as :



The cations (Na^+) pass into the solution while the anions ($\text{C}_{15}\text{H}_{31}\text{COO}^-$) have a tendency to form aggregates due to weak attractive forces present in the hydrocarbon chains.

(iii) **Due to selective adsorption of ions.** The particles constituting the dispersed phase *adsorb only those ions preferentially which are common with their own lattice ions*. For example, if a dilute solution of silver nitrate is added to an aqueous solution of potassium iodide, the precipitated silver iodide will adsorb negative I^- ions (common ions) from the dispersion medium to form a **negatively charged sol**. This is shown in Fig. 26 (a).



In this case, the left out ions (K^+) will remain in the dispersion medium thereby giving equal and opposite charge (positive) to the dispersion medium.

However, if silver iodide is formed by adding a dilute solution of potassium iodide to silver nitrate solution, the sol will be **positively charged** due to the adsorption of Ag^+ ions (common ions) present in the dispersion medium.

NOTE

Tyndall effect can be used to distinguish between a true solution and a colloidal solution. A strong beam of light is passed through the given solution. If the path of the light gets illuminated, the solution is a colloidal solution. On the other hand, if the path of the light does not get illuminated, it is a true solution.

Thus,

Colloidal solutions \Rightarrow show Tyndall effect

True solutions \Rightarrow do not show Tyndall effect.

It may be noted that among colloids, lyophilic colloids do not show Tyndall effect but lyophobic colloids show Tyndall effect.

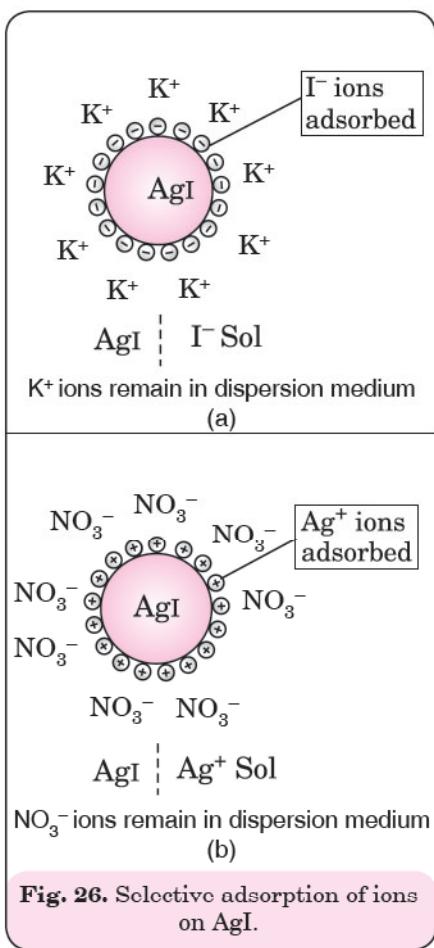
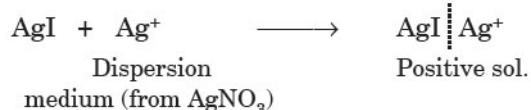


Fig. 26. Selective adsorption of ions on AgI.



The left out ions (NO_3^-) will remain in the dispersion medium thereby giving equal and opposite charge (negative) to the dispersion medium [Fig. 26 (b)].

Thus,

the ion which is common with their own lattice ions is preferentially adsorbed.

Similarly, if ferric chloride is added to excess of hot water, a positively charged sol of hydrated ferric hydroxide is formed. This is because of adsorption of Fe^{3+} ions. However, when ferric chloride is added to sodium hydroxide (NaOH) solution, a negatively charged sol is obtained due to the adsorption of OH^- ions.



Based on the nature of the charge, the colloidal solutions have been classified into positively charged and negatively charged colloids. Some common examples are listed in Table 5.

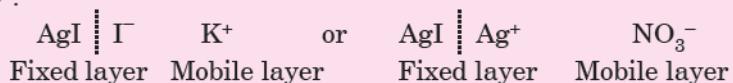
Table 5. Some common positively and negatively charged colloidal solutions.

| Positively charged sols | Negatively charged sols |
|---|---|
| Hydrated metallic oxides e.g., $\text{Al}_2\text{O}_3 \cdot x\text{H}_2\text{O}$, $\text{Cr}_2\text{O}_3 \cdot x\text{H}_2\text{O}$, $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$, etc. | Metallic particles e.g., Cu, Ag, Au, Pt, sols |
| Metal hydroxides e.g., Fe(OH)_3 , Al(OH)_3 , Cr(OH)_3 , Ca(OH)_2 . | Metal sulphides e.g., As_2S_3 , CdS , Sb_2S_3 , etc. |
| Basic dye stuffs like methylene blue, prussian blue | Acidic dyes like eosin, congo red, etc. |
| Haemoglobin (blood) | Sols of starch, gum, gelatin, clay, charcoal, etc. |
| Oxides e.g., TiO_2 sol. | |

Learning Plus

THEORY OF ELECTRICAL DOUBLE LAYER

Colloidal dispersions possess electrical properties which are due to their ability to adsorb from solution ions, molecules of medium or both. The adsorbed phase controls the stability of the sol and its behaviour in electric field. To explain this, a theory of electrical double layer was first proposed by Helmholtz in 1879. According to this theory, when a solid comes in contact with a liquid (e.g., a solution of an electrolyte) it preferentially adsorbs one type of ions on its surface. This forms a fixed layer. To counter balance this charge, oppositely charged ions are attracted to the surface to form a double layer of charges. For example, as explained above, AgI sol becomes positively charged or negatively charged by selective adsorption on the surface of the colloidal particles. This layer attracts the counter ions from the medium forming a second layer as shown below :



Such an arrangement of charges is called **Helmholtz double layer**. Fig. 27 (a) and leads to a difference of electric potential between the solid and the liquid. In this theory, the charges next to the surface were considered to be

fixed while the compensating charges in the liquid were thought to be **mobile**.

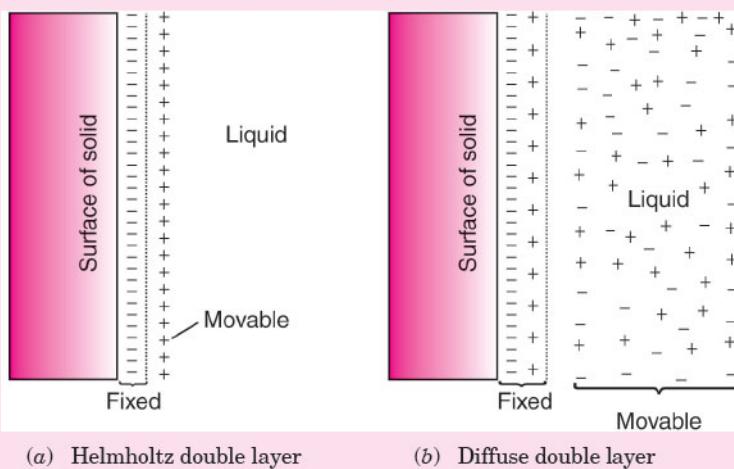


Fig. 27

However, according to modern views, some of the compensating charges are held in the stationary liquid layer adhering to the surface. The remaining charges are distributed next to this layer in the form of a diffuse or mobile layer as shown in Fig. 27. (b). This mobile layer along with the fixed layer (containing charges fixed on the surface as well as some compensating charges) constitute **diffuse electrical double layer**. The potential difference that exists between the stationary layer of compensating charges and the diffuse layer (present in the body of the solution) is called **electrokinetic** or **zeta potential**. This is involved in various nonstatic electrical properties of solid-liquid interfaces and is also responsible for the electrical effects observed in colloids.

The electrical properties of colloidal solutions are related with two phenomena:

- (i) Electrophoresis
- (ii) Electroosmosis

(i) **Electrophoresis** : The presence of the charge on the sol particles and its nature whether positive or negative can be determined with the help of a phenomenon known as **electrophoresis**. In this experiment, the colloidal particles move towards positive or negative electrodes depending upon their charge under the influence of electrical field.

The phenomenon of movement of colloidal particles under an applied electric field is called electrophoresis.

If the particles accumulate near the negative electrode, the charge on the particles is **positive**. On the other hand, if the sol particles accumulate near the positive electrode, the charge on the particles is **negative**.

The apparatus consists of U-tube with two platinum electrodes in each limb (Fig. 28). Take a sol of As_2S_3 in the U-tube. The intensity of the colour of the sol in both the arms is same. Now pass the current through the sol. After some time, it is observed that the colour of the sol near the positive electrode became intense than the initial colour. This indicates that the As_2S_3 particles have accumulated near the positive electrode. In other words, the particles of As_2S_3 are negatively charged and they move towards oppositely charged (positive) electrode and accumulate there.

Similarly, when an electric current is passed through positively charged $\text{Fe}(\text{OH})_3$ sol, it is observed that they move towards negatively charged electrode and get accumulated there.

Thus, by observing the direction of movement of the colloidal particles, the sign of the charge carried by the particles can be determined.

(ii) **Electro-osmosis** : When the movement of the colloidal particles is prevented by some suitable means and the molecules of the dispersion medium are allowed to move under the influence of applied potential, the phenomenon is called electro-osmosis.

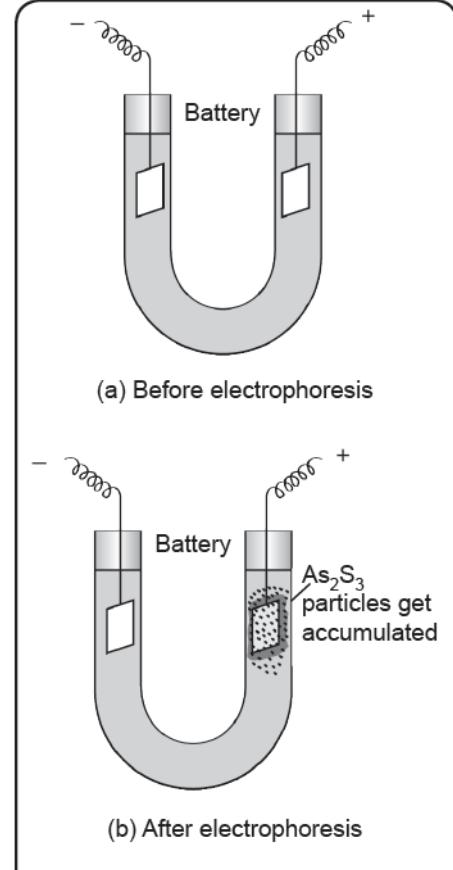


Fig. 28. Process of electrophoresis.

Thus, **electro-osmosis** is the phenomenon of the movement of the molecules of the dispersion medium under the influence of electric field whereas colloidal particles are not allowed to move.

The electroosmosis can be observed by a simple apparatus as shown in Fig. 29. The colloidal solution is placed in a compartment A separated from compartments B and C by semipermeable membranes D and D'. The compartments B and C are filled with water up to the marks indicated by the side arms. When a potential is applied across the two electrodes placed near the membranes in B and C, the liquid level is observed to fall on one side and rise on the other side due to the passage of water through membrane D and D'. The direction of the flow of water depends on the charge of the colloid. For positively charged sols the medium is negatively charged, and hence the flow will take place from C to B. On the other hand, for negatively charged sols, the reverse will occur and the level on the C side will rise.

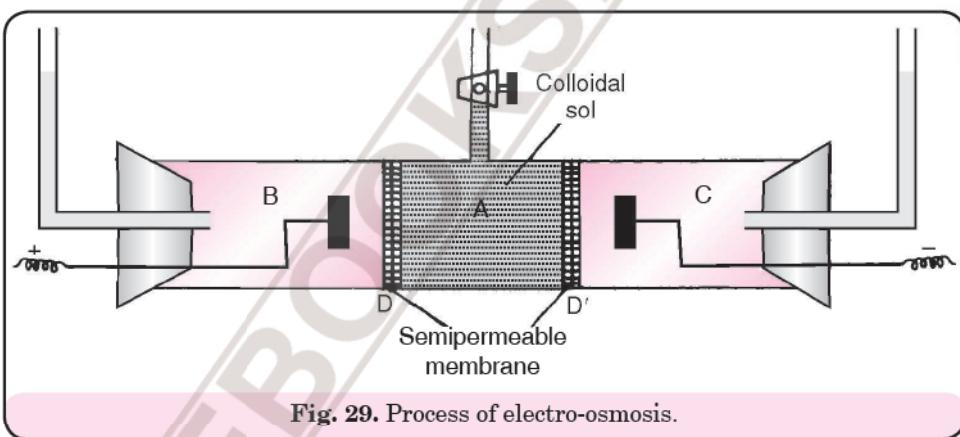


Fig. 29. Process of electro-osmosis.

COAGULATION OF COLLOIDAL SOLUTIONS

We know that a small amount of an electrolyte is necessary for the stability of the colloidal sol. The ions of the electrolytes are adsorbed on the sol particles and impart them some charge; positive or negative. The charged colloidal particles repel one another and are prevented from coming close together to unite into bigger particles (Fig. 30). If, somehow, the charge is removed, the particles will come nearer to each other to form aggregate (or coagulate) and settle down under the force of gravity. For example, in the presence of a large excess of the electrolyte, the charge on the particles of the dispersed phase is neutralised and as a result, they come closer, grow in size and ultimately form precipitates. This is called precipitation or coagulation. Thus,

the phenomenon of precipitation of a colloidal solution by the addition of excess of an electrolyte is called **coagulation** or **flocculation**.

Mechanism of coagulation. The particles of the dispersed phase i.e., colloids bear some charge. When an electrolyte is added to the sol, the colloidal particles take up ions carrying opposite charge from the electrolyte. As a result, their charge gets neutralised and this causes the uncharged particles to come closer and to get coagulated or precipitated. For example, if BaCl_2 solution is added to As_2S_3 sol, the Ba^{2+} ions are attracted by the negatively charged sol particles and their charge gets neutralised. This leads to coagulation.

Hardy Schulze rule.

The coagulation tendency of different electrolytes is different. It depends upon the valency of the *active ion* called *flocculating ion*, which is the ion carrying charge opposite to the charge on the colloidal particles. According to **Hardy Schulze rule**, *greater the valency of the active ion or flocculating ion, greater will be its coagulating power*.

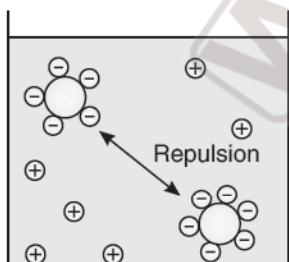
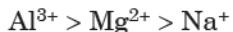


Fig. 30. Repulsion between colloidal particles gives stability.

Thus, according to Hardy Schulze rule :

- The ions carrying the charge opposite to that of sol particles are effective in causing coagulation of the sol.*
- Coagulating power of an electrolyte is directly proportional to the fourth power of the valency of the active ions (ions causing coagulation). Greater is the valency of the oppositely charged ion of the electrolyte being added, the faster is the coagulation.*

For example, to coagulate **negative sol of As_2S_3** , the coagulating power of different cations has been found to **decrease** in the order as :



Similarly, to coagulate a **positive sol**, such as Fe(OH)_3 , the coagulating power of different anions has been found to **decrease in the order** :



The minimum concentration of an electrolyte in millimoles which is required to cause the coagulation or flocculation of one litre of a sol is known as **coagulation value or flocculation value**.

It is usually expressed as millimoles per litre. Thus, **smaller is the coagulation value of an electrolyte, greater is its coagulation or flocculation power**. For example, the coagulation values (in millimoles/litre) for the coagulation of positively charged Fe(OH)_3 sol and negatively charged As_2S_3 sol are given in Table 6.

Table 6. Coagulation values (in millimoles/litre) of common electrolytes.

| Ferric hydroxide (+) sol | | | Arsenic sulphide (-) sol | | |
|-----------------------------------|-----------------------------|--------------------------------------|--------------------------|---------------------|--------------------------------------|
| Electrolyte | Active ion (anion) | Coagulation value (millimoles/litre) | Electrolyte | Active ion (cation) | Coagulation value (millimoles/litre) |
| KBr | Br^- | 138 | NaCl | Na^+ | 51 |
| KCl | Cl^- | 103 | KCl | K^+ | 50 |
| KNO_3 | NO_3^- | 131 | MgSO_4 | Mg^{2+} | 0.72 |
| K_2SO_4 | SO_4^{2-} | 0.210 | BaCl_2 | Ba^{2+} | 0.69 |
| $\text{Na}_2\text{C}_2\text{O}_4$ | $\text{C}_2\text{O}_4^{2-}$ | 0.238 | ZnCl_2 | Zn^{2+} | 0.68 |
| $\text{K}_3[\text{Fe(CN)}_6]$ | $[\text{Fe(CN)}_6]^{3-}$ | 0.096 | AlCl_3 | Al^{3+} | 0.093 |

The above table shows that the coagulating power is inversely proportional to coagulation value or flocculation value. The relative coagulating powers may be compared as :

$$\frac{\text{Coagulating power of electrolyte 1}}{\text{Coagulating power of electrolyte 2}} = \frac{\text{Coagulating value of electrolyte 2}}{\text{Coagulating value of electrolyte 1}}$$

For example, for coagulation of negatively charged As_2S_3 sol.

$$\frac{\text{Coagulating power of } \text{AlCl}_3}{\text{Coagulating power of NaCl}} = \frac{\text{Coagulating value of NaCl}}{\text{Coagulating value of AlCl}_3}$$

$$= \frac{51}{0.093} = 548$$

Thus, AlCl_3 has 548 times more coagulating power than NaCl.

A few other methods for coagulation

Apart from the addition of the electrolyte, the coagulation of a colloidal sol can be affected by the following methods :

(i) **By mutual precipitation.** When two oppositely charged sols are mixed in equimolar proportions, they mutually neutralise their charge and both get coagulated. For example, if positively charged Fe(OH)_3 sol and negatively charged As_2S_3 sol are mixed, both the sols get coagulated.

(ii) **By electrophoresis.** We have seen in the electrophoresis that the particles of the dispersed phase move towards the oppositely charged electrodes. If the process is carried for a long time the particles will touch the electrode, lose their charge and get coagulated.

REMEMBER

Smaller is the coagulation or flocculation value of an electrolyte, greater is its **coagulation or flocculation power**.

(iii) **By persistent dialysis.** The stability of colloidal sols is due to the presence of a small amount of electrolyte. If the electrolyte is completely removed by repeated dialysis, the particles left will get coagulated.

(iv) **By heating or cooling.** In certain cases, the sols get coagulated on heating. For example, coagulation of butter. Similarly, in some cases cooling the sol also results into its coagulation. For example, coagulation of milk i.e., on cooling milk fats start floating on the surface.

Coagulation of Lyophilic sols.

Lyophilic sols are more stable than lyophobic sols. The stability of lyophilic sols is due to two factors :

(i) Charged and

(ii) Solvation of the colloidal particles.

When these two factors are removed, a lyophilic sol can be coagulated. This can be done (i) by adding electrolyte and (ii) by adding suitable solvent. For example, when solvents such as alcohol or acetone are added to hydrophilic sols, it results into dehydration of dispersed phase. Under this condition, a small quantity of electrolyte can cause coagulation.

SOLVED EXAMPLES

Example 6.

In a coagulation experiment, 5 mL of As_2S_3 is mixed with distilled water and 0.1 M solution of an electrolyte AB so that total volume is 10 mL. It was found that all solutions containing more than 4.6 mL of AB coagulate within 5 minutes. What is the flocculation value of AB for As_2S_3 sol.?

Solution : A minimum of 4.6 mL of AB is required to coagulate the sol. The moles of AB in the sol is

$$= \frac{4.6 \times 0.1}{10} = 0.046 \text{ moles}$$

This means that a minimum of 0.046 moles or $0.046 \times 1000 = 46$ millimoles are required for coagulating 1 litre of sol.

\therefore Flocculation value of AB for As_2S_3 sol. = 46

PROTECTION OF COLLOIDS

Lyophobic sols such as those of metals like gold, silver etc. can be easily precipitated by the addition of a small amount of electrolytes. They can be prevented from coagulation by the previous addition of some stable lyophilic colloids like gelatin, albumin, etc. This is because when a lyophilic sol is added to the lyophobic sol, the lyophilic particles form a layer around the lyophobic particles and this protects them from electrolytes as shown in Fig. 31. For example, if a small amount of gelatin is added to gold sol, it is not readily precipitated by the addition of sodium chloride. *This process of protecting the lyophobic colloidal solutions from precipitation by the electrolytes due to the previous addition of some lyophilic colloid is called protection.* The colloid which is added to prevent coagulation of the colloidal sol is called **protecting colloid**.

The protecting power of different protective (lyophilic) colloids is expressed in terms of gold number.

Gold number. The different protecting colloids differ in their protecting powers. Zsigmondy introduced a term called **gold number** to describe the protective power of different colloids. This is defined as

the minimum amount of the protective colloid in milligrams required to just prevent the coagulation of a 10 mL of a given gold sol when 1 mL of a 10% solution of sodium chloride is added to it.

The coagulation of gold sol is indicated by change in colour from **red to blue**. The gold numbers of a few protective colloids are as given in Table 7.



Competition Plus

At **isoelectric point of colloids**, the lyophilic colloids, are expected to have minimum mobility. For detail, refer **Competition File**, (Page 65).

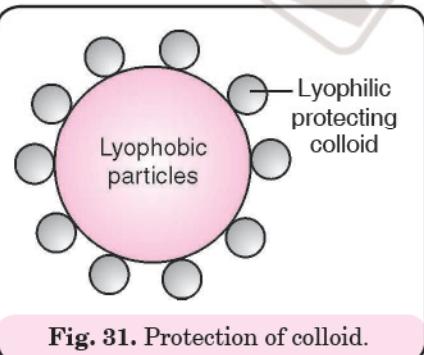


Fig. 31. Protection of colloid.

Table 7. Gold numbers of some protective colloids.

| Sol | Gold number |
|-------------|--------------|
| Gelatin | 0.005 – 0.01 |
| Casein | 0.01 – 0.02 |
| Haemoglobin | 0.03 – 0.07 |
| Egg albumin | 0.1 – 0.2 |
| Gum arabic | 0.15 – 0.25 |
| Starch | 20 – 25 |
| Dextrin | 6 – 20 |

REMEMBER

- The smaller the value of gold number, greater will be the protecting power of the protective colloid i.e.,
- Protective power of a colloid is reciprocal of the gold number.

It may be noted that smaller the value of the gold number, greater will be protecting power of the protective colloid. Therefore, reciprocal of gold number is a measure of the protective power of a colloid. Thus, out of the list given above, gelatin is the best protective colloid.

SOLVED EXAMPLES**Example 7.**

The coagulation of 100 mL of a colloidal solution of gold is completely prevented by the addition of 0.25 g of starch to it before adding 1 mL of 10% NaCl solution. Calculate the gold number of starch. (Hr. S.B. 2004)

Solution : Amount of starch added to 100 mL of gold sol required to prevent coagulation of 1 mL of 10% NaCl solution

$$= 0.25 \text{ g}$$

or

$$= 250 \text{ mg}$$

Starch required to be added to 10 mL of gold sol. to completely prevent coagulation by 1 mL of 10% NaCl solution

$$= \frac{25}{100} \times 10 = 2.5 \text{ mg}$$

$$\therefore \text{Gold number of starch} = 25$$

EMULSIONS

Emulsions are the colloidal solutions in which both the dispersed phase and the dispersion medium are liquids.

In other words, emulsions are liquid-liquid colloidal systems i.e., the dispersion of finely divided droplets in another liquid. Any two immiscible liquids form an emulsion. For example, milk is a naturally occurring emulsion in which the particles (or globules) of liquid fats are dispersed in water.

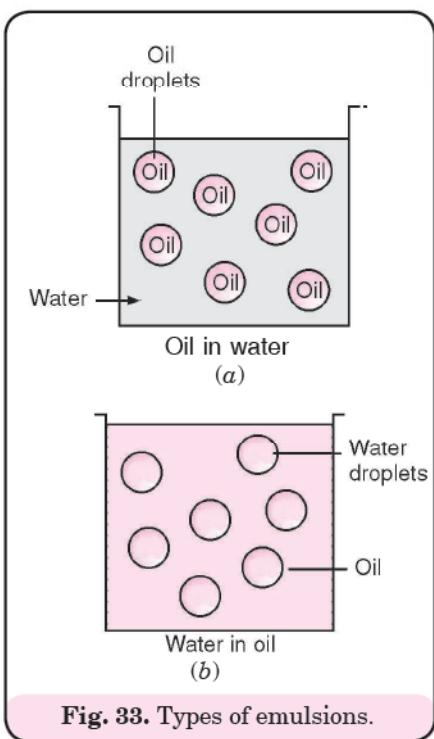
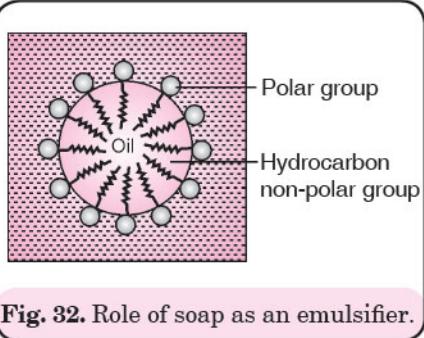
Emulsions are generally prepared by vigorously shaking two liquids or by passing the mixture through a colloid mill, called the homogenizer. Since the two do not mix well, the emulsion is generally unstable and the two liquids may separate out on standing for some time. Therefore, to form stable emulsions, small quantities of certain other substances are added during their preparation. The substances which are added to stabilize the emulsions are called **emulsifier** or **emulsifying agent**. The substances that are commonly used as emulsifying agents are gum, soap of different forms, gelatin, albumin, etc.

Role of emulsifier. The stabilisation of an emulsion by means of emulsifier is called **emulsification**.

The main function of the emulsifier is to reduce the interfacial tension between the two liquids forming the emulsion. Emulsifiers are generally long chain molecules having polar groups.

Congo Rubin Number

It may be noted that sometimes the protective action of a lyophilic colloid is expressed as **Congo Rubin Number** instead of gold number. It was suggested by Ostwald and is expressed as the minimum amount of the protective colloid in milligrams that prevents the colour change of 100 mL of 0.01% congo rubin dye to which 0.16 gram equivalent of KCl is added.



R U Curious...



- Both vanishing cream and cold cream are emulsions. Are these different or same?
- Vanishing cream is an emulsion of oil-in-water whereas cold cream is an emulsion of water-in-oil. Cold cream is used for dry skin as the base (dispersion medium) in this is oil.

The role of emulsifier can be explained by taking the example of soap as an emulsifier. As already studied, the soaps are sodium or potassium salts of higher fatty acids such as sodium palmitate ($C_{15}H_{31}COONa$), sodium stearate ($C_{17}H_{35}COONa$), etc. A molecule of soap consists of two parts : hydrocarbon non-polar part (e.g., $C_{15}H_{31}$, $C_{17}H_{35}$, etc.) which is soluble in oil and the polar group ($-COO^-Na^+$) which is soluble in water.



When a drop of oil is surrounded by soap solution, R-part of the soap remains in oil and the COO^-Na^+ part remains in water as shown in Fig. 32. As a result, soap molecules get concentrated over the surface of the drop of oil and therefore form protective film around each oil drop. As a result, the interfacial tension between oil and water decreases and therefore they are intermixed to form the emulsion.

Casein (a protein), a lyophobic colloid present in milk acts as an emulsifying agent as it forms a protective layer around fat molecules dispersed in water. Therefore, milk is a fairly stable emulsion.

Types of Emulsions. These are of two types :

(i) **Oil-in-water (o/w type) emulsions.** In this case, oil acts as the dispersed phase (small amount) and water as the dispersion medium (excess) [Fig. 33 (a)]. For example, milk is an emulsion of soluble fats in water and here casein acts as an emulsifier. Vanishing cream is another example of this class. Such emulsions are called **aqueous emulsions**.

(ii) **Water-in-oil (w/o type) emulsions.** In this case, water acts as the dispersed phase while the oil behaves as the dispersion medium [Fig. 33 (b)]. For example, butter, cod liver oil, cold cream, etc. Such types of emulsions are called **oily emulsions**.

It may be noted that the two types of emulsions can be interconverted by simply changing the ratio of the dispersed phase and dispersion medium. For example, an oil-in-water emulsion can be converted to water-in-oil emulsion by simply adding excess of oil in the first case.

Identification of emulsions

The oil in water or water in oil type emulsions can be identified by the following tests :

(i) **Dilution test.** Add water to the emulsion. If the emulsion can be diluted with water, this means that water acts as the dispersion medium and it is an example of oil-in-water emulsion. In case, it is not diluted, then oil acts as dispersion medium and it is an example of water-in-oil emulsion.

(ii) **Dye test.** An oil soluble suitable dye is shaken with the emulsion. If colour is noticed on looking at a drop of the emulsion, it is oil-in-water type emulsion. In case the entire background is coloured, it is an example of water-in-oil type.

Applications of emulsions

(i) **Concentration of ores in metallurgy.** The concentration of the sulphide ore of a metal by froth floatation process involves the use of some oil such as pine oil. The oil forms emulsion with ore particles. When air is bubble through the emulsion, it rises to the surface as foam and is skimmed off.

(ii) **In medicine.** The various pharmaceuticals and cosmetics available in liquid form such as cod-liver oil, B-complex, ointments etc. are emulsions of water-in-oil type. These are readily adsorbed in the intestines.

(iii) **Cleansing action of soaps.** The cleansing action of soap is based upon the formation of oil-in-water type emulsion.

(iv) **Milk.** Milk which is an important constituent of our diet is an emulsion of fat in water.

Demulsification. It is the process of decomposing an emulsion back into its constituent liquids. The demulsification can be done by centrifugation, filtration, boiling, freezing and some chemical methods. For example :

- (i) Cream from milk is separated by centrifugation.
- (ii) Fat can be removed from milk by cooling it in a refrigerator.

Properties of emulsions

(i) Emulsions show all the characteristic properties of colloidal solution such as Brownian movement, Tyndall effect, electrophoresis, etc.

(ii) These are coagulated by the addition of electrolytes containing polyvalent metal ions indicating the negative charge on the globules.

(iii) The size of the dispersed particles in emulsions is larger than those in the sols. It ranges from 1000 \AA to $10,000\text{ \AA}$. However, the size is smaller than the particles in suspensions.

(iv) Emulsions can be broken (or converted) into two separate liquids by heating, centrifuging, freezing, etc. This process is also known as demulsification.

GELS

A **gel** is a colloidal system in which a liquid is dispersed in a solid. Under certain conditions, the lyophilic sols may be coagulated to give a semi solid jelly like mass which encloses all the liquid present in the sol. The process of gel formation is called **gelation** and the colloidal system formed is called **gel**. The common examples of gel are : *gum arabic, gelatin, processed cheese, silicic acid, ferric hydroxide, etc.*

Gels may be classified into two types :

- (i) **Elastic gels**
- (ii) **Non-elastic gels.**

(i) **Elastic gels.** These are the gels which possess the property of elasticity. They readily change their shape on applying force and return to original shape when the applied force is removed. They change to solid mass on dehydration which can again be converted into gel by addition of water followed by heating and cooling. When these gels are placed in contact with water, they absorb water and swell. This property is called **imbibition**. Common examples are gelatin, agar, starch etc.

(ii) **Non-elastic gels.** These are the gels which are rigid and do not have the property of elasticity. They change into solid mass on dehydration which becomes rigid and cannot be converted into original form by heating with water. Unlike elastic gels they do not show the phenomenon of imbibition. For example, silica gel.

COLLOIDS AROUND US

We come across many phenomena of colloids in our day to day life. Some of these are:

1 **Blue colour of the sky and sea.** Blue colour of the sky is due to the scattering of light by colloidal dust particles present in the air (Tyndall effect). These dust particles alongwith water suspended in air scatter blue light which reaches our eyes and therefore, sky looks blue to us. This is because blue colour of white sunlight has minimum wavelength and hence shows more intense scattering. Similarly, sea water looks green due to scattering of light by the colloidal impurities present in sea water.

2. **Fog, mist and rain.** When a large mass of air containing dust particles is cooled below its dew point, the moisture present in the air condenses on the surface of these particles and form fine droplets. These droplets are colloidal in nature and continue to float in the air in the form of mist or fog.

Clouds are aerosols having small droplets of water being suspended in air. Because of condensation in the upper atmosphere, the colloidal droplets of water become bigger and bigger in size till they fall down in the form of rain. Sometimes, the rainfall occurs when two oppositely charged clouds collide.

Learning Plus

- Colloidal sol of gold in water is called **purple of cassius**.
- Colloidal sol of silver is called **argyrol** and is used as eye lotion.
- Colloidal antimony is used for curing **kalazar**.
- Colloidal Fe(OH)_3 is given to a person having poisoning due to arsenic because it absorbs arsenic and then can be vomited out.
- Colloidal solution of graphite in water is called **aqua dag** and that in oil is called **oil dag**.
- **Collodion** is a 4% solution of cellulose nitrate in a mixture of ethyl alcohol and ether.
- Substances such as soaps which possess surface activity i.e., exhibit the property to lower the surface tension of the liquid and therefore, increase its surface are called **surfactants**.

R U Curious...



Sky looks blue!

Sky looks blue due to scattering of light by colloidal dust particles. Since blue colour of sunlight has minimum wavelength, it shows more intense scattering. The scattered blue light reaches our eyes and, therefore, sky looks blue to us.

3. Food articles. Many food articles such as milk, butter, ice-creams fruit juices, fruit jellies, whipped cream, etc. are colloidal in nature.

4. Soils. Fertile soils are also colloidal in nature. In the soil, the humus acts as a protective colloid. Because of colloidal nature soils adsorb moisture and other nourishing substances.

5. Dyeing. In the dyeing of fabrics, the fabric is first treated with a colloidal suspension of a substance called **mordant** (e.g., aluminium hydroxide). The mordant should be such that it gets strongly adsorbed on the fabric and then the dye gets strongly adsorbed on it. As a result, the dye sticks fast to the fabric.

6. Varnishes, paints, enamels, resins, cellulose gums, glues, soaps, detergents, etc. are all colloidal in nature.

7. Asphalt emulsified on water is used for building roads without the necessity of melting the asphalt is colloid.

8. Formation of delta. River water is muddy and contains charged colloidal particles of clay, sand and many other materials. Sea water contains in it a number of dissolved electrolytes. When the river water comes in contact with the sea water, the electrolytes present in sea water coagulate the suspended colloidal particles which ultimately settle down at the point of contact. As a result, the level of the river bed rises. As a result, water adopts a different course and delta is formed in due course of time at the point where the river enters the sea.

9. Tail of comets. Tail behind a comet is seen as Tyndall cone due to scattering of light by the tiny solid particles of colloidal range left by the comet in its path.

10. Blood. It is a colloidal solution of an albuminoid substance. Bleeding stops when alum and ferric chloride solution is applied to a bleeding part. The styptic action of alum or ferric chloride is due to coagulation of blood by an electrolyte forming a blood clot which stops further bleeding.

APPLICATIONS OF COLLOIDS

Colloids play a vital role in our daily life. The applications, in general, are based upon the presence of the charge on the colloidal particles.

1. Electrical precipitation of smoke. In big cities, the factories work round the clock and the smoke coming out of the chimneys contain a lot of unburnt carbon particles. Smoke is a colloidal solution of solid particles such as carbon, arsenic compounds, dust, etc. in air. These are quite injurious to health and have to be precipitated from the smoke. In fact, smoke is a colloidal system in which the carbon particles are suspended in air. The carbon particles are charged in nature and they do not get coagulated or precipitated.

The charge on the carbon particles is neutralised by bringing them in contact with the oppositely charged metal plate. They thus, get precipitated and the smoke coming out of the chimney is free from dust. This precipitation of smoke particles is carried out by **Cottrell smoke precipitator** shown in Fig. 34. In this method, the smoke is allowed to pass through a chamber having a series of plates charged to very high potential (20,000 to 70,000 V). Charged particles of smoke get attracted by charged plates, get precipitated and the gases coming out of chimney become free of charged particles.

2. Sewage disposal. The sewage disposal contains particles of dirt, rubbish, etc. suspended in water. They are, therefore, colloidal in nature and are also charged. These particles do not settle down easily. The particles can be removed by discharging them at electrodes. The dirty water is either placed in big tanks or passed through a tunnel fitted with metallic electrodes which are maintained at high potential difference. The colloidal particles migrate towards the oppositely charged electrodes where their charge is neutralised and they get coagulated. The coagulated mass can be used as a manure and the water left behind is used for irrigation.

3. Purification of drinking water. The water coming from natural sources often contains suspended impurities. The drinking water can be purified by precipitation of suspended colloidal particles. For this purpose, a small amount of alum $[K_2SO_4 Al_2(SO_4)_3 \cdot 24H_2O]$ is added. The Al^{3+} ions neutralise the charge on the particles and they get coagulated.

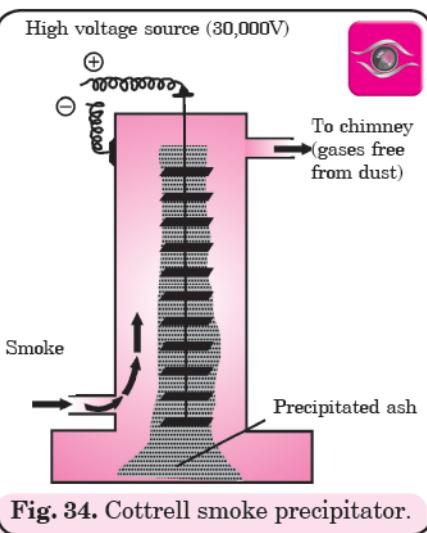


Fig. 34. Cottrell smoke precipitator.

STEM AND TECHNOLOGY

Colloidal particles in a sol are very small and most of them are not visible through an ultramicroscope or light microscope. Recently, new techniques have been developed to determine the size and shape of the colloidal particles. These are :

- (i) *Scanning Electron Microscope (SEM)*
- (ii) *Transmission Electron Microscope (TEM)*

A modified form of the above methods has also been developed. It is called *Scanning Transmission Electron Microscope (STEM)*. All these techniques are superior to the light microscope because they have greater resolving power.

4. Colloidal medicines. A wide variety of medicinal and pharmaceutical preparations are emulsions. The colloidal medicines are quite effective on account of their easy assimilation and adsorption. A few important medicines are colloidal gold, manganese, sulphur, antimony, etc. For example,

- (i) Argyrol is a silver sol used as an eye lotion.
- (ii) Colloidal antimony is used for curing disease kala azar.
- (iii) Milk of magnesia, an emulsion is used for stomach disorders.
- (iv) Colloidal gold is used for intramuscular injection. Colloidal medicines are more effective because these have large surface area and therefore, are easily assimilated with blood, which is colloidal.
- (v) Ferric chloride is quite effective to stop bleeding from a minor cut. It coagulates the blood due to its charged nature.

5. Tanning. Animal hides are colloidal in nature and have positively charged particles. Tannin, which is obtained from plants contains negatively charged colloidal particles. When animal hides are soaked in tannin, their mutual coagulation takes place. This results in hardening of leather. This process of hardening of leather is called **tanning**. Chromium salts are also used in place of tannin.

6. In disinfectants. The disinfectants such as dettol and lysol give emulsions of the oil-in-water when mixed with water.

7. Photographic plates and films. These are thin glass plates or celluloid films coated with gelatin containing a fine suspension of silver bromide. The particles of silver bromide are colloidal in nature.

8. Chemical warfare. Smoke or mist screens are formed by the dispersion of harmful substances by explosion of bombs, etc. They are very injurious to health. Gas masks are essential to filter out the toxic smokes. These masks contain in them colloidal animal charcoal to adsorb the poisonous gases.

9. Artificial rain. Artificial rain can be caused by spraying oppositely charged colloidal dust or sand particles over a cloud from an aeroplane. The colloidal water particles present in the cloud will get neutralised and will coagulate to form bigger water drops causing artificial rain.

10. Rubber industry. Latex is a colloidal solution of negatively charged colloidal rubber particles. Rubber can be obtained from latex by coagulation. These rubber particles can be deposited over articles (wares or handles of different tools) to be rubber plated by electrophoresis. The article to be rubber plated is made the anode in the rubber plating bath. Rubber gloves are formed by rubber plating on suitable templates.

11. In metallurgical operations. Emulsions play an important role in industry. The metal ores are concentrated by froth-floatation process which involves the treatment of the pulverised ore in emulsion of pine oil.

add on

Conceptual Questions 2

**C
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QA

Q. 1. Why are lyophilic colloidal sols more stable than lyophobic colloidal sols ?

(D.S.B. 2015)

Ans. The lyophilic colloidal sols. are more stable because they are highly hydrated in solution.

Q. 2. Give one test to distinguish whether the given emulsion is oil in water type or water in oil type emulsion.

Ans. It can be identified by dilution test. In this method, the emulsion is diluted with water. If the emulsion gets diluted with water, this means that water acts as the dispersion medium and it is an example of oil in water emulsion. If, it is not diluted than oil acts as dispersion medium and it is an example of water in oil emulsion.

Q. 3. What is observed when sodium chloride is added to a colloidal solution of ferric hydroxide ?

Ans. When sodium chloride is added to ferric hydroxide sol., the sol. gets coagulated. This is because the Cl^- ions from NaCl neutralise the +ve charge on Fe(OH)_3 sol.

Q. 4. Give an example of (i) micelles system (ii) macromolecular colloid.

Ans. (i) Sodium stearate ($\text{C}_{17}\text{H}_{35}\text{COO}^-\text{Na}^+$). (ii) Proteins.

Q. 5. What is the difference between a sol and a gel ?

(D.S.B. 2017)

Ans. In a sol, dispersion medium is liquid and dispersed phase is solid. On the other hand, in a gel, dispersion medium is solid and dispersed phase is liquid.

Q. 6. What is the difference in the nature of a dilute soap solution and a concentrated soap solution ?

Ans. Dilute soap solution behaves like a true solution whereas concentrated soap solution behaves like a colloidal solution.

Q. 7. What happens when a colloidal sol of Fe(OH)_3 and As_2O_3 are mixed ?

Ans. Their mutual precipitation takes place.

Q. 8. The conductance of an emulsion increases on adding common salt. What type of emulsion is this ?

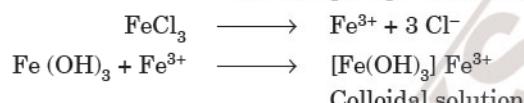
Ans. Oil in water type emulsion.

Q. 9. What happens when a freshly precipitated Fe(OH)_3 is shaken with little amount of dilute solution of FeCl_3 ?

(Hr. S.B. 2004)

Ans. A reddish brown colloidal solution of Fe(OH)_3 is obtained. This process is called peptization.

The Fe^{3+} ions from FeCl_3 are adsorbed on the surface of the precipitate and form positively charged colloidal solution.



Q. 10. What type of colloid is formed when a liquid is dispersed in a solid? Give an example. (A.I.S.B. 2017)

Ans. Gel

For example: Cheese

Q. 11. What does reciprocal of gold number indicate ?

Ans. Reciprocal of gold number is a measure of protective power of a colloid. Smaller the value of gold number, greater will be its protecting power.

Q. 12. 50 mL of standard gold sol. needs 0.05 mg of gelatin for its protection from coagulation. Calculate gold number of gelatin.

Ans. 50 mL of gold sol. require gelatin for protection from coagulation = 0.05 mg

10 mL of gold sol. will require gelatin for protection from coagulation = 0.005 mg

\therefore Gold number of gelatin = 0.005.

Q. 13. 100 mL of a colloidal solution is completely precipitated by addition of 5 mL of 1 M NaCl solution. Calculate the coagulation value of NaCl. (Hr. S.B. 2004)

Ans. Coagulation value is the millimoles of an electrolyte that must be added to 1 L of a colloidal solution for complete coagulation.

$$\therefore 5 \text{ mL of } 1 \text{ M NaCl} = \frac{1}{1000} \times 5 = 0.005 \text{ or } 5 \text{ m moles.}$$

100 mL of a colloidal solution require NaCl for complete coagulation = 5 m moles

\therefore 1 L of colloidal solution require NaCl for complete coagulation = 50 m moles

\therefore Coagulation value of NaCl = 50.

Q. 14. What is the charge on the colloidal particles in the following :

(i) Fe(OH)_3 sol (ii) As_2S_3 sol (iii) Colloidal sol of silver ?

Ans. (i) Fe(OH)_3 sol : +ve

(ii) As_2S_3 sol : -ve

(iii) Colloidal sol of silver : -ve.

Q. 15. Which of the following is most effective electrolyte in the coagulation of $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}/\text{Fe}^{3+}$ sol ?

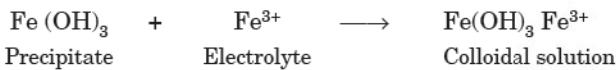
KCl, AlCl_3 , MgCl_2 , $\text{K}_4[\text{Fe CN}]_6$ (CBSE Sample Paper 2011)

Ans. Since Fe(OH)_3 sol is positively charged, the anion having highest charge will be most effective i.e., $[\text{Fe}(\text{CN})_6]^{3-}$.

Q. 16. Peptizing agent is added to convert precipitate into colloidal solution. Explain.

(CBSE Sample Paper 2011)

Ans. Peptisation is a process of converting a freshly prepared precipitate into colloidal form by the addition of an electrolyte called peptising agent. The suitable ions from the peptising agent (electrolyte) are adsorbed by the particles of the precipitate giving it positive or negative charge. The charged particles repel one another and break up the precipitate into smaller particles of the size of the colloid. Therefore, it results into the formation of colloid. For example, on treating a precipitate of iron (III) oxide with a small amount of FeCl_3 solution gives a reddish brown coloured colloidal solution.



Q. 17. Cottrell's smoke precipitator is fitted at the mouth of chimney used in factories. Give reasons.

(CBSE Sample Paper 2011)

Ans. Smoke coming out of chimney of a factory is a colloidal solution of soild carbon particles which are charged in nature. The mouth of the chimneys used in factories is fitted with Cottrell smoke precipitator. In this method, the smoke is allowed to pass through a chamber having a series of plates charged to very high potential (20,000 to 70,000 V). Charged particles of smoke get attracted by charged plates, get precipitated and the gases coming out of chimney become free of charged carbon and dust particles.

Q. 18. Why is colloidal gold used for intramuscular injection ?

(CBSE Sample Paper 2011)

Ans. Colloidal gold is more effective because of larger surface area and therefore, is easily assimilated with blood which is colloidal.

Q. 19. What is colloidion ?

(CBSE Sample Paper 2011)

Ans. 4% solution of nitrocellulose in a mixture of alcohol and ether.

Q. 20. Differentiate between peptization and coagulation.

(CBSE Sample Paper 2011, A.I.S.B.2017)

Ans. Peptization is the process of converting a freshly prepared precipitate into colloidal form by the the addition of a suitable electrolyte. The electrolytes used for the purpose are called peptizing agents. On the other hand, coagulation is the phenomenon of precipitation of a colloidal solution by the addition of excess of an electrolyte.

Q. 21. Why is ferric chloride preferred over potassium chloride in case of a cut leading to bleeding ?

Ans. Fe^{3+} is a better coagulating ion than K^+ due to larger positive charge on it.

Q. 22. Explain :

(i) **Sky appears blue in colour.**

(ii) **A freshly formed precipitate of ferric hydroxide can be converted to a colloidal sol by shaking it with a small quantity of ferric chloride.** *(CBSE Sample Paper 2011)*

Ans. (i) Dust particles alongwith water suspended in air scatter blue light which reaches our eyes and therefore, sky looks blue to us.
(ii) When we add FeCl_3 to a freshly formed precipitate of Fe(OH)_3 , peptisation occurs. The Fe^{3+} ions are adsorbed on the surface of the precipitate which ultimately breaks down into smaller particles of colloidal size.

Q. 23. Leather gets hardened after tanning. Why?

(D.S.B. 2015)

Ans. Animal hide is colloidal in nature and has positively charged particles. When it is soaked in tanin which has negatively charged colloidal particles, it results in mutual coagulation. This results in the hardening of leather.

Q. 24. It is necessary to remove CO when ammonia is prepared by Haber's process. Explain. *(D.S.B. 2015)*

Ans. Carbon monoxide acts as a poison for the catalyst in Haber's process and therefore, it will lower the activity of the catalyst. Thus, CO must be removed when ammonia is obtained by Haber's process.

Q. 25. Addition of alum purifies water. Why?

(A.I.S.B. 2015)

Ans. Alum coagulates the impurities present in water by neutralising the charge.

Q. 26. Out of MgCl_2 and AlCl_3 which one is more effective in causing coagulation of negatively charged sol and why? *(D.S.B. 2016)*

Ans. According to Hardy Schulze rule, for negatively charged sol, greater the valency of the positive ion of the electrolyte added, greater is its coagulating power. Thus, AlCl_3 (Al^{3+} ion) is more effective in causing coagulation of negatively charged sol than MgCl_2 (Mg^{2+} ions).

Q. 27. Out of sulphur sol and proteins, which one forms multimolecular colloids? *(D.S.B. 2016)*

Ans. Proteins are macromolecules which cannot form multimolecular colloids while sulphur sol has smaller S_8 molecules which can coagulate to form multimolecular colloids.

Q. 28. Write the dispersed phase and dispersion medium of milk. *(A.I.S.B. 2017)*

Ans. Dispersed phase: Liquid

Dispersion medium: Liquid

Q. 29. Write the chemical method by which Fe(OH)_3 sol is prepared from FeCl_3 . *(A.I.S.B. 2017)*

Ans. $\text{FeCl}_3(s) + 3\text{H}_2\text{O} \xrightarrow{\text{Hydrolysis}} \text{Fe(OH)}_3(\text{sol}) + 3\text{HCl}$

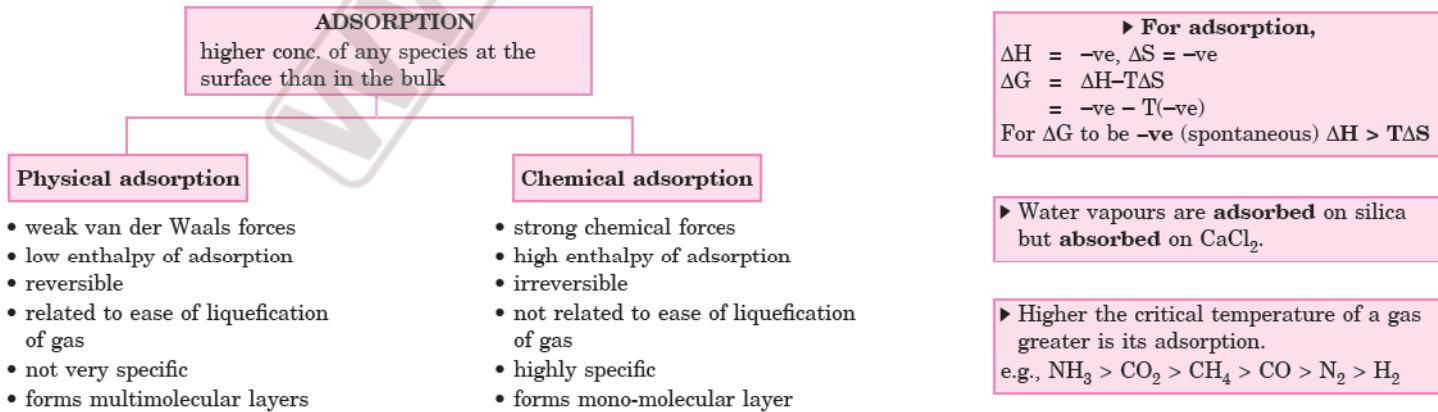


Chapter Summary

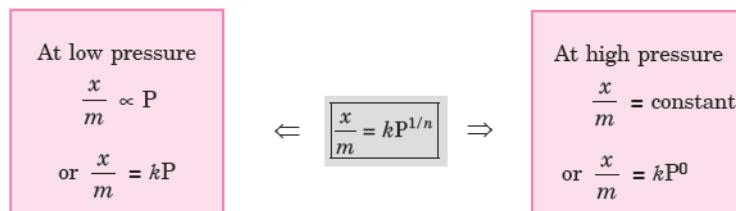
Key Terms & Laws

- **Adsorption.** The phenomenon of higher concentration of molecular species (gases or liquids) on the surface of a solid than in the bulk.
- **Occlusion.** The adsorption of a gas on the surface of a metal.
- **Adsorbent.** The substance on which adsorption takes place.
- **Adsorbate.** The substance adsorbed.
- **Colloidal solution.** A heterogeneous solution which contains particles having diameters between 1 to 1000 nm. These are intermediate between true solutions and suspensions.
- **Lyophilic colloids.** The colloidal solutions in which the particles of the dispersed phase have a great affinity for the dispersion medium.
- **Lyophobic colloids.** The colloidal solutions in which the particles of the dispersed phase have no affinity for the dispersion medium.
- **Micelles.** These are the cluster or aggregated particles formed by association of colloids in solution.
- **Dialysis.** It is the process of separating particles of colloids from those of crystalloids by means of diffusion through a membrane.
- **Brownian movement.** The random zig zag motion of colloidal particles.
- **Electrophoresis.** The phenomenon of movement of colloidal particles under an applied electric field.
- **Coagulation.** The process of changing the colloidal particles in a sol. into the insoluble precipitate by the addition of some suitable electrolytes is known as **coagulation**.
- **Peptisation.** Conversion of a freshly precipitated substance into colloidal sol. by shaking with a suitable electrolyte is called **peptisation**.
- **Gold number.** The minimum number of milligrams of a lyophilic sol. needed to protect 10 mL of gold sol. by the addition of 1 mL of 10% NaCl is called **gold number**. Protective power is the reciprocal of gold number.
- **Emulsions** are colloidal systems in which both dispersed phase and dispersion medium are liquids.
- **Emulsification.** The process of making emulsion is called **emulsification**.
- **Gel.** A colloidal system in which a liquid is dispersed in a solid.

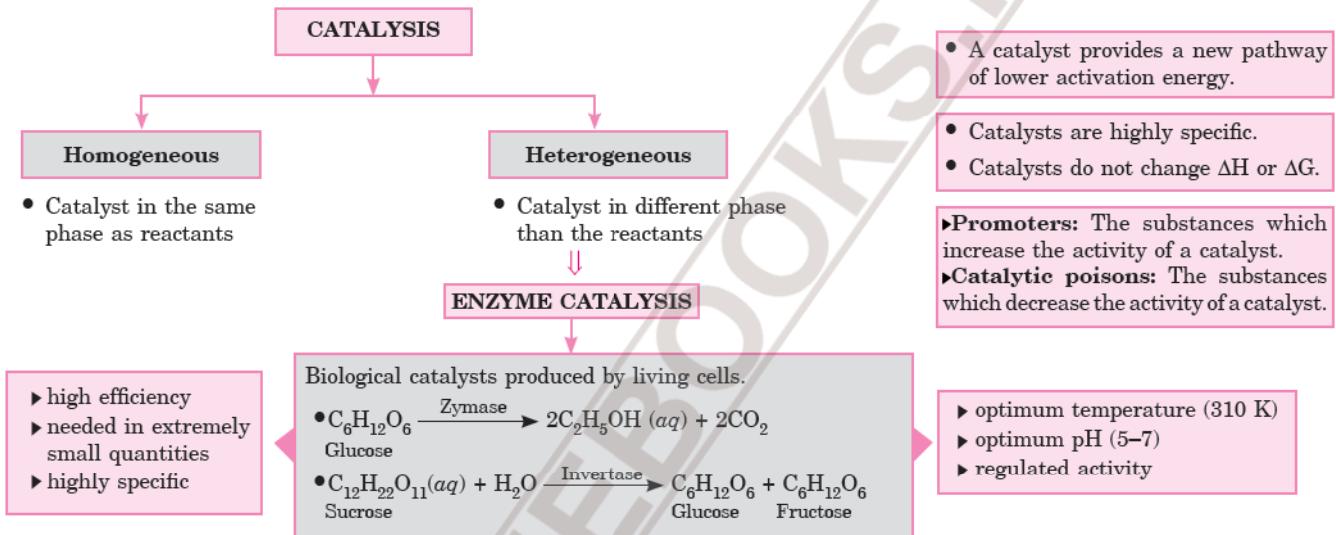
QUICK CHAPTER ROUND UP



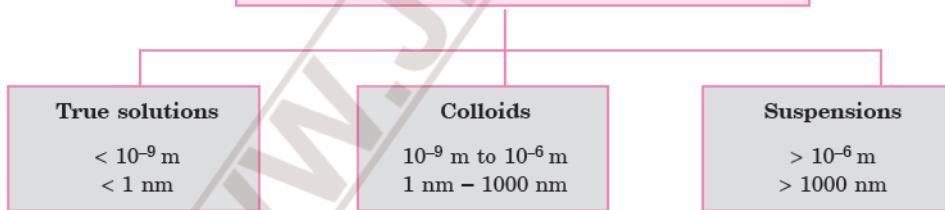
Freundlich adsorption isotherm



► Plot of $\log \frac{x}{m}$ vs $\log P$ gives slope = $\frac{1}{n}$ and intercept = $\log k$

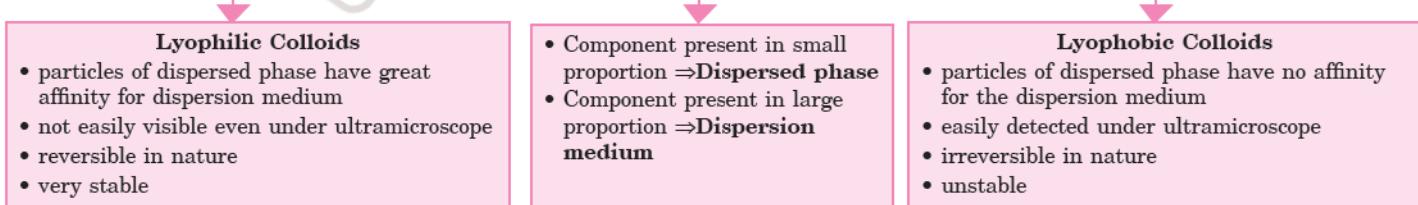


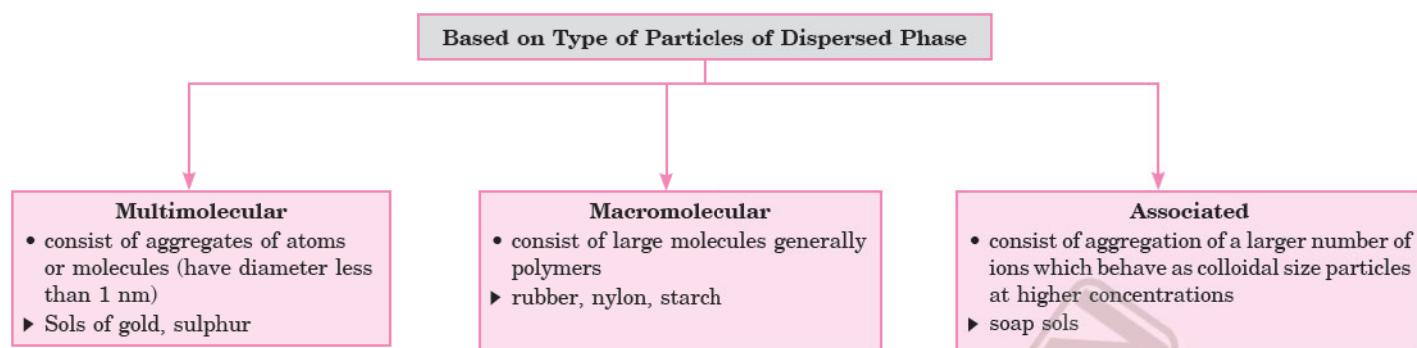
SIZES OF PARTICLES OF SOLUTIONS



COLLOIDS

Based on Nature of Interactions between Dispersed Phase and Dispersion Medium





Aggregated ion particles formed by association of colloids in solution are called **ionic micelles**. The conc. above which these are formed is called **critical micellisation concentration (CMC)**. The temp. above which these are formed is called **Kraft temp. (T_k)**

Colloidal solutions are heterogeneous consisting of two phases

Colloidal solutions show:

- Brownian movement
- Tyndall effect
- Electrical properties
- Have charge

+ very charged Sol

- metallic hydroxides; Fe(OH)_3 , Al(OH)_3 , Cr(OH)_3
- metallic oxides; $\text{Al}_2\text{O}_3 \cdot x\text{H}_2\text{O}$

- very charged Sol

- metallic particles Cu, Ag, Au, Pt
- sulphides As_2S_3 , Sb_2S_3

Electrophoresis helps to study the charge carried by the particles.

HARDY SCHULZE RULE

- ion carrying charge opposite to sol particles coagulate the sol

For negative sol like As_2S_3
 $\text{Al}^{3+} > \text{Mg}^{2+} > \text{Na}^+$

For positive sol like Fe(OH)_3
 $[\text{Fe(CN)}_6]^{4-} > \text{PO}_4^{3-} > \text{SO}_4^{2-} > \text{Cl}^-$

The minimum number of millimoles of the electrolyte required for coagulation of 1L of colloidal sol is called **coagulation value** or **flocculation value**.

The smaller is the coagulation value of an electrolyte, greater is its coagulation power.

GOLD NUMBER

- minimum amount of protective colloid required to prevent coagulation
- smaller the value of gold number, greater is the protective power of protective colloid.
- Protective power of a colloid is reciprocal of gold number

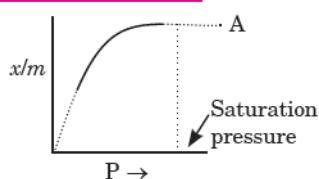
EMULSIONS

- Colloidal solution in which dispersed phase and dispersion medium are liquids
- **Oil in water type**
e.g., milk, vanishing cream
- **Water in oil type** e.g. butter, cold cream

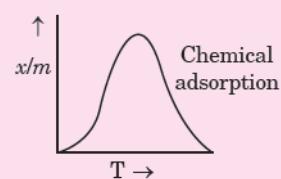
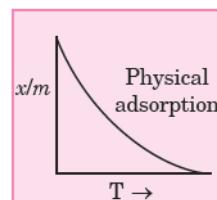
GEL

- colloidal system in which a liquid is dispersed in a solid.
e.g., gelatin, processed cheese, gum arabic

Important Graphs



⇒





NCERT FILE

Solved



NCERT

In-text Questions

Q.1. Why are substances like platinum and palladium often used for carrying out electrolysis of aqueous solutions ?

Ans. Platinum and palladium are often used for carrying out electrolysis because these are inert in nature and the products of electrolysis easily get adsorbed or deposited over these metals. Therefore, products can be easily collected.

Q.2. Why does physisorption decrease with the increase of temperature ?

Ans. In physisorption, the attractive forces between adsorbent and adsorbate molecules are weak van der Waals forces. When temperature is increased, the kinetic energy of the molecules of the gas increases and they can easily leave the surface of adsorbent because of weak forces of attraction.

Q.3. Why are powdered substances more effective adsorbent than their crystalline forms ?

Ans. This is because powdered substances have more surface area as compared to their crystalline forms. Greater the surface area, greater is the adsorption.

Q.4. Why is it necessary to remove CO when ammonia is obtained by Haber's process ?

Ans. Carbon monoxide acts as a poison for the catalyst in Haber process and therefore, it will lower the activity of the catalyst. Thus, CO must be removed when ammonia is obtained by Haber's process.

Q.5. Why is the ester hydrolysis slow in the beginning and becomes faster after sometime ?

Ans. This is because of the process of autocatalysis. Ester on hydrolysis gives an acid which starts acting as a catalyst after sometime and therefore, the reaction becomes fast.

Q.6. What is the role of desorption in the process of catalysis ?

Ans. In the process of catalysis, when desorption occurs from the surface of the catalyst, the surface becomes ready to adsorb fresh reactants and act as a catalyst.

Q.7. What modification can you suggest in Hardy Schulze law ?

Ans. The Hardy Schulze law considers the coagulation of sols because of neutralization of their charges. Since coagulation can also occur by mixing two oppositely charged sols, it should also include "when oppositely charged sols are mixed in proper proportions to neutralize the charges of each other, the coagulation of both the sols occurs".

Q.8. Why is it essential to wash the precipitate with water before estimating it quantitatively ?

Ans. The precipitates may be contaminated with the adsorbed particles of some other substances (impurities) which might have been used or formed during precipitation. Therefore, it is essential to wash the precipitate to remove these adsorbed particles.



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Textbook Exercises

Q.1. Distinguish between the meaning of the terms adsorption and absorption. Give one example of each.

Ans. Adsorption is a phenomenon in which there is higher concentration of another substance on the surface than in the bulk. Absorption is a phenomenon in which the molecules of a substance are uniformly distributed throughout the body of the other substance.

For example, silica gel adsorbs water vapour while anhydrous calcium chloride absorbs water.

Q.2. What is the difference between physisorption and chemisorption ?

Ans. Refer Text Page 6.

Q.3. Give reason why a finely divided substance is more effective as an adsorbent.

Ans. Finely divided substance has larger surface area and hence greater adsorption.

Q.4. What are the factors which influence the adsorption of a gas on a solid ?

Ans. Refer Text Page 7.

Q.5. What is an adsorption isotherm ? Describe Freundlich adsorption isotherm.

Ans. Adsorption isotherm represents the variation of the mass of the gas adsorbed per gram of the adsorbent with pressure at constant temperature.

For Freundlich adsorption isotherm, refer Text Page 9.

Q.6. What do you understand by activation of adsorbent? How is it achieved ?

Ans. Activation of adsorbent means the increasing of the adsorbing power of the adsorbent. *For detail see Text Page 8.*

Q.7. What role does adsorption play in hetero-geneous catalysis?

Ans. In heterogeneous catalysis, the reactants are generally gases while catalysts are solids. The reactant molecules are adsorbed on the surface of the solid catalyst by physical adsorption or chemical adsorption. As a result, the concentration of the reactant molecules on the surface of the catalyst increases and hence the rate of reaction also increases.

Alternatively, one of the reactant molecules undergo fragmentation on the surface of the catalyst producing active sites which make the reaction fast. The product molecules, on the other hand, have no affinity for the solid catalyst and therefore, undergo desorption leaving the surface free for further fresh adsorption. This theory is called adsorption theory.

Q.8. Why is adsorption always exothermic ?

Ans. Adsorption occurs because of attraction between adsorbate and adsorbent molecules and therefore, energy is always released during adsorption. Hence adsorption is an exothermic process.

Q.9. How are the colloidal solutions classified on the basis of physical states of the dispersed phase and dispersion medium ?

Ans. Refer Text Page 26.

Q.10. Discuss the effect of pressure and temperature on the adsorption of gases on solids.

Ans. Refer Text Page 8.

Q.11. What are lyophilic and lyophobic sols ? Give one example of each type. Why is lyophobic sols easily coagulated ?

Ans. The lyophobic sols are less stable because their stability is due to charge only. If the charge is removed, the particles will come nearer to each other to form aggregates i.e., they will coagulate and settle down. On the other hand, the stability of lyophilic sols is due to charge as well as solvation of colloidal particles. Therefore, these are not easily coagulated.

Q.12. What is the difference between multimolecular and macromolecular colloids ?

Give one example of each. How are associated colloids different from these two types of colloids ?

Ans. The important differences between multimolecular and macromolecular colloids are :

| Multimolecular | Macromolecular |
|--|--|
| 1. The colloidal particles consist of aggregates of a large number of atoms or molecules having diameter less than 1nm. 2. Particles are held by weak van der Waals forces. | The colloidal particles are macromolecules having very large molecular mass. |
| | They consist of macromolecular particles held by chemical bonds. |

The common example of multimolecular colloid is sulphur sol, which consists of particles of S_8 molecules. The common example of macromolecule is starch.

The associated colloids are substances which behave as normal electrolytes at low concentrations but behave as colloidal particles at higher concentration. For example, soap and detergents.

They differ from multimolecular and macromolecular colloids in the sense that they behave as normal electrolytes at low concentrations but exhibit colloidal state properties at higher concentrations due to the formation of aggregated particles called micelles.

Q.13. What are enzymes ? Write in brief the mechanism of enzyme catalysis.

Ans. Enzymes are complex nitrogenous organic compounds produced by living cells which catalyze the biochemical reactions occurring in living organisms. These are also called biological catalysts or bio-chemical catalysts.

For detail Refer Text Pages 19–22.

Q.14. How are colloids classified on the basis of (a) physical states of components, (b) nature of dispersion medium, and (c) interaction between dispersed phase and dispersion medium ?

Ans. (a) **Classification of colloids on the basis of physical states of components.** The colloids can be classified on the basis of physical state of dispersion medium and dispersed phase. For detail, refer Text Section Page 26.

(b) **Classification on the basis of nature of dispersion medium.** Depending upon the nature of the dispersion medium, the colloidal solutions are classified as :

(i) **Aquasol or hydrosol** : when dispersion medium is water.

(ii) **Alcosol** : when dispersion medium is alcohol.

(iii) **Benzosol** : when dispersion medium is benzene.

(iv) **Aerosol** : when dispersion medium is air.

(c) **Classification on the basis of nature of interactions between dispersed phase and dispersion medium.** These may be classified as

(i) Lyophilic sols and (ii) lyophobic sols.

For detail refer Page 27 type B.

Q.15. Explain what is observed

(i) when a beam of light is passed through a colloidal sol., (ii) an electrolyte, $NaCl$ is added to hydrated ferric oxide sol. (iii) electric current is passed through a colloidal sol. ?

Ans. (i) Scattering of light by colloidal particles takes place and path of light becomes visible (Tyndall effect).

(ii) The positively charged colloidal particles of $Fe(OH)_3$ get coagulated by the oppositely charged Cl^- ions provided by $NaCl$.

(iii) On passing electric current, the colloidal particles move towards the oppositely charged electrode where they lose their charge and get coagulated. This is electrophoresis process.

For details of these, refer Text Page 39–40.

Q.16. What are emulsions? What are their different types ? Give one example of each type.

Ans. Refer Text Page 43–44.

Q.17. What is demulsification ? Name two demulsifiers.

Ans. The process of separation of constituent liquids of an emulsion is called de-emulsification.

De-emulsification can be done by (i) boiling or (ii) centrifugation.

Q.18. Action of soap is due to emulsification and micelle formation. Comment.

Ans. Refer Text Page 31.

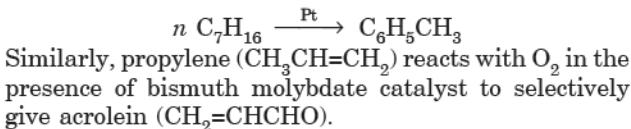
Q.19. Give four examples of heterogeneous catalysis.

Ans. Refer Text Page 16.

Q.20. What do you mean by activity and selectivity of catalysts ?

Ans. Activity means the ability of catalysts to increase the chemical reaction. A common example of activity is the reaction H_2 and O_2 to form water in the presence of platinum. Without the presence of the catalyst, the mixture of H_2 and O_2 can be safely stored. But in the presence of catalyst, the reaction occurs with explosive violence. In some cases the catalyst can accelerate the reaction to as high as 10^8 times.

The selectivity means the ability of the catalyst to direct reaction to give particular products. For example, *n*-heptane in the presence of platinum catalyst gives toluene.

**Q.21. Describe some features of catalysis by zeolites.**

Ans. Zeolites are microporous aluminosilicates of the general formula $\text{M}_{x/n}[(\text{AlO}_2)_x(\text{SiO}_4)_y]m\text{H}_2\text{O}$. These are most important oxide catalysts. These are used in petrochemical industries for cracking of hydrocarbons and isomerization. The reactions in zeolites depend upon the size of the cavities (cages) or pores (apertures) present in them. The most remarkable feature of zeolite catalysis is the shape selectivity. Therefore, the selectivity of catalyst depends on the pores structure. It has been observed that the pore size in zeolites generally varies between 260 pm to 740 pm. Depending upon the size of the reactants and products compared to the size of the cages or pores of zeolite, reactions proceed in specific manner.

A zeolite catalyst called ZSM-5 converts alcohols to gasoline, by first dehydrating the alcohol by loss of water.

Q.22. What is shape selective catalysis ?

Ans. The catalysis by zeolites is called shape selective catalysis. For details refer Text Page 23.

Q.23. Explain the following terms : (i) Electrophoresis (ii) Coagulation (iii) Dialysis (iv) Tyndall effect.

Ans. Refer Text.



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Note: Objective Questions from Exemplar Problems are given in Competition File, page 74.

» **Short Answer Type Questions** «

1. Why is it important to have clean surface in surface studies ?

Ans. Clean surface facilitates the adsorption of desired species and help in surface studies.

2. Why is chemisorption referred to as activated adsorption ?

Ans. Chemisorption involves formation of bond between gaseous atoms or molecules and the solid surface. This requires high activation energy. Thus, it is referred to as activated adsorption.

3. What type of solutions are formed on dissolving different concentrations of soap in water ?

Ans. At lower concentration soap forms a normal electrolytic solution with water. After a certain concentration called critical micelle concentration, colloidal solution is formed.

4. What happens when gelatin is mixed with gold sol ?

Ans. Gold sol is a lyophobic sol. Addition of gelatin stabilises the sol.

5. How does it become possible to cause artificial rain by spraying silver iodide on the clouds ?

Ans. Clouds are colloidal in nature and carry charge. Spray of silver iodide, (an electrolyte) on the clouds results in coagulation leading to artificial rain.

Q.24. Give four uses of emulsions.

Ans. Refer Text Page 44.

Q.25. What are micelles ? Give an example of a micellar system.

Ans. Refer Page 29.

Q.26. Explain the terms with suitable examples :

(i) Alcosol (ii) Aerosol and (iii) Hydrosol.

Ans. (i) **Alcosol.** It is a colloid sol of a solid in alcohol as dispersion medium.

(ii) **Aerosol.** It is a colloidal dispersion of a liquid in a gas e.g., fog.

(iii) **Hydrosol.** It is a colloidal sol of a solid in water as dispersion medium.

Q.27. Comment on the statement that “colloid is not a substance but a state of substance”.

Ans. Colloid is not a substance but it is a state of substance. This statement means a particular substance may exist as a colloid under certain conditions and as a crystalloid under other conditions. For example, sodium chloride in water behaves as a crystalloid while in benzene, it behaves as a colloid. Similarly, dilute soap solution behaves like a crystalloid while the concentrated solution behaves as a colloid (called associated colloid). It is the size of the particle that decides the state in which the substance exists. If the size of the particles lies in the range of 10 nm to 100 nm, it is in the colloidal state.

Exemplar Problems // / Subjective Questions

6. Gelatin which is a peptide is added in ice creams. What can be its role ?

Ans. Ice creams are emulsions which get stabilised by emulsifying agents such as gelatin.

7. What is collodion ?

Ans. It is a 4% solution of nitrocellulose in a mixture of alcohol and ether.

8. Why do we add alum to purify water ?

Ans. The colloidal impurities present in water get coagulated by added alum. This makes water potable.

9. What happens when electric field is applied to colloidal solution ?

Ans. The charged colloidal particles start moving towards oppositely charged electrodes.

10. What causes brownian motion in colloidal dispersion ?

Ans. Unbalanced bombardment of the particles of dispersed phase by molecules of dispersion medium causes Brownian motion. This stabilises the sol.

11. A colloid is formed by adding FeCl_3 in excess of hot water. What will happen if excess sodium chloride is added to this colloid?

Ans. Positively charged sol of hydrated ferric oxide is formed and on adding excess of NaCl, negatively charged chloride ions coagulate the positively charged sol of hydrated ferric oxide.

12. How do emulsifying agents stabilise the emulsion ?

Ans. The emulsifying agent forms an interfacial layer between suspended particles and the dispersion medium thereby stabilising the emulsion.

13. Why are some medicines more effective in the colloidal form ?

Ans. Medicines are more effective in the colloidal form because of large surface area and are easily assimilated in this form.

14. Why does leather get hardened after tanning ?

Ans. Animal hide is colloidal in nature and has positively charged particles. When it is soaked in tanin which has negatively charged colloidal particles, it results in mutual coagulation.

15. How does the precipitation of colloidal smoke take place in Cottrell precipitator ?

Ans. In Cottrell precipitator, charged smoke particles are allowed to pass through a chamber having a series of plates charged to very high potential (20,000 to 70,000 V) opposite to the smoke particles. Smoke particles lose their charge on the plates and get precipitated. Therefore, the gases coming out of the chimney become free of charged particles.

16. How will you distinguish between dispersed phase and dispersion medium in an emulsion ?

Ans. On adding dispersion medium, emulsions can be diluted to any extent. The dispersed phase forms a separate layer if added in excess.

17. On the basis of Hardy-Schulze rule explain why the coagulating power of phosphate is higher than chloride.

Ans. The minimum quantity of an electrolyte required to cause coagulation of a sol is called its coagulating value. According to Hardy-Schulze rule, greater the charge on flocculating ion and smaller is the amount of electrolyte required for precipitation, higher is the coagulating power of coagulating ion.

18. Why does bleeding stop by rubbing moist alum ?

Ans. Moist alum coagulates the blood and forms blood clot. This stops bleeding.

19. Why is Fe(OH)_3 colloid positively charged, when prepared by adding FeCl_3 to hot water ?

Ans. The adsorption of positively charged Fe^{3+} ions by the sol of hydrated ferric oxide results in positively charged colloid.

20. Why do physisorption and chemisorption behave differently with rise in temperature ?

Ans. Physisorption involves weak van der Waals forces which decrease with rise in temperature. The chemisorption involves formation of chemical bond involving activation energy and is favoured by rise in temperature like any other chemical reaction.

21. What happens when dialysis is prolonged ?

Ans. When dialysis is prolonged, the traces of electrolyte which stabilises the colloids are removed completely. This makes the colloid unstable and therefore coagulation takes place.

22. Why does the white precipitate of silver halide become coloured in the presence of dye eosin?

Ans. The dye eosin is adsorbed on the surface of silver halide precipitate. Therefore, the precipitate is coloured.

23. What is the role of activated charcoal in gas mask used in coal mines ?

Ans. Activated charcoal acts as an adsorbent for various poisonous gases present in the coal mines.

24. How does a delta form at the meeting place of sea and river water ?

Ans. River water is muddy and contains charged particles of clay, sand and other materials. When the river water comes in contact with sea water, the electrolytes present in sea water coagulate the suspended colloidal particles which ultimately settle down at the point of contact. The point at which river and sea meet is the site for coagulation. The deposition of coagulated clay results in delta formation.

25. Give an example where physisorption changes to chemisorption with rise in temperature. Explain the reason for change.

Ans. The process of physisorption for example that of H_2 on finely divided nickel, involves weak van der Waals' forces. With increase in temperature, hydrogen molecules dissociate into hydrogen atoms which are held on the surface by chemisorption.

26. Why is desorption important for a substance to act as good catalyst ?

Ans. After the reaction is complete between adsorbed reactants, the process of desorption is important to remove products and further create space for the other reactant molecules to approach the surface and react.

27. What is the role of diffusion in heterogenous catalysis ?

Ans. The gaseous molecules diffuse on to the surface of the solid catalyst and get adsorbed. After the required chemical changes the products diffuse away from the surface of the catalyst leaving the surface free for more reactant molecules to get adsorbed and undergo reaction.

28. How does a solid catalyst enhance the rate of combination of gaseous molecules ?

Ans. When gaseous molecules come in contact with the surface of a solid catalyst, the gaseous molecules are held with the surface of the catalyst by weak forces on the surface. This increases the concentration of reactants on the surface. Different molecules adsorbed side by side have better chance to react and form new molecules. This increases the rate of reaction. Moreover, adsorption is an exothermic process. The heat released in the process of adsorption is utilised in increasing the reaction rate.

29. Do the vital functions of the body such as digestion get affected during fever ? Explain your answer.

Ans. The optimum temperature range for enzymatic activity is 298-310 K. When the temperature is below or above this temperature range, enzymatic activity gets affected. Thus, during fever, when temperature rises above 310 K, the activity of enzymes may be affected.



QUICK

MEMORY TEST



A. Say True or False

1. Physical adsorption increases with rise in temperature whereas chemical adsorption decreases with rise in temperature.
2. Chemisorption is irreversible while physisorption is reversible.
3. Selectivity is the ability of a catalyst to direct the reaction to give a particular product.
4. At low pressure, the extent of adsorption is directly proportional to pressure at constant temperature.
5. $\text{Al}(\text{NO}_3)_3$ has higher coagulating power than MgSO_4 for Fe(OH)_3 sol.
6. Gel is a system in which liquid is the dispersed phase and solid is the dispersion medium.
7. Greater the gold number of a protective colloid, greater is its protecting power.
8. Greater the flocculation value of an electrolyte, greater is its coagulating power.
9. Adsorption is always multimolecular.
10. Colloidal sols are always heterogeneous.

B. Complete the missing links

1. Milk is an example of in emulsion.
2. The process in which adsorption and absorption take place simultaneously is called
3. The nature of forces involved in physical adsorption are
4. The formation of micelles takes place above a particular temperature called
5. The movement of colloidal particles under the influence of an electric field is called
6. The scattering of light by colloidal particles is called
7. The swelling of gel in water is called

Answers

QUICK

MEMORY TEST



A. Say True or False

1. False 2. True 3. True 4. True
5. **False.** Fe(OH)_3 is a positive sol. and therefore, SO_4^{2-} ion (MgSO_4) has higher coagulation power than NO_3^- ion [$\text{Al}(\text{NO}_3)_3$].
6. True.
7. **False.** Protecting power varies inversely as gold number.
8. **False.** Greater the flocculation value of an electrolyte, lesser is its coagulating power.

8. is the process of separating the crystalloids from colloids using an animal membrane.
9. Colloidal solution of gold in water is called
10. In whipped cream, the dispersion medium is and dispersed phase is
11. In benzosol, the dispersion medium is
12. The size of particles of colloidal solution is in the range of nm to
13. A graph between the amount of gas adsorbed per gram of the absorbent and equilibrium pressure of the adsorbate at constant temperature is called
14. The rate of adsorption in general is in the beginning and then till equilibrium is attained.
15. The formation of micelles takes place above a particular concentration called

C. Choose the correct alternative

1. Adsorption is exothermic/endothermic process.
2. Chemisorption always form unimolecular/multimolecular layer.
3. According to Freundlich adsorption isotherm, x/m becomes independent of pressure at low/high pressure.
4. The size of colloidal particles is less/more than that of true solution particles.
5. Substances like gum, starch form lyophilic/lyophobic sols.
6. The formation of micelles occurs only above/below Kraft temperature.
7. Multimolecular colloids have lyophilic/lyophobic character.
8. Colloidal solutions form homogeneous/heterogeneous mixtures.
9. When ferric chloride is added to sodium hydroxide solution, negative/positive sol is formed.
10. Gelatin (gold number 0.005–0.01) has more/less protecting power than albumin (gold number 0.1–0.2).

9. **False.** Physisorption is multimolecular but chemisorption is unimolecular.

10. True.

B. Complete the missing links

1. liquid, liquid 2. sorption
3. van der Waals forces 4. Kraft temperature
5. electrophoresis
6. Tyndall effect
7. imbibition

8. dialysis
 9. purple of cassius
 11. benzene
 13. adsorption isotherm
 14. high, decreases
 15. critical micelle concentration
10. liquid, gas
 12. 1,1000

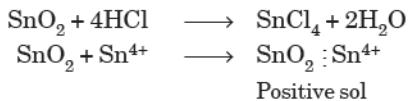
C. Choose the correct alternative

1. exothermic
2. unimolecular
3. high
4. more
5. lyophilic
6. above
7. lyophobic
8. heterogeneous
9. negative
10. more.

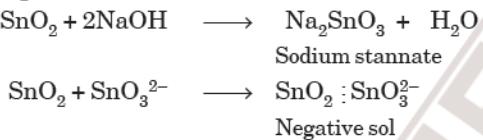
HOTS**Higher Order Thinking Skills & Advanced Level****QUESTIONS WITH ANSWERS**

Q.1. SnO_2 forms a positively charged colloidal solution in acidic medium and a negatively charged colloidal solution in basic medium. Explain.

Ans. SnO_2 is amphoteric in nature and reacts with acids as well as bases. It reacts with acids, e.g., HCl to form SnCl_4 in solution. The common Sn^{4+} ions are adsorbed on the surface of SnO_2 forming positively charged sol :



SnO_2 reacts with a base e.g., NaOH to form sodium stannate (Na_2SnO_3) in the solution. The stannate ions are adsorbed on the surface of SnO_2 to form negatively charged sol.



Q.2. Why is chemical adsorption unimolecular while physical adsorption is multimolecular?

Ans. Chemical adsorption takes place as a result of chemical reaction between adsorbent and adsorbate. When the surface of adsorbent is covered with one layer, no further reaction can take place. Therefore, chemical adsorption is unimolecular. On the other hand, physical adsorption is due to van der Waals forces between adsorbent and adsorbate molecules. So any number of layers can be formed one over the other on the surface of the adsorbent. Therefore, physical adsorption is multimolecular.

Q.3. Adsorption of a gas on the surface of solid is generally accompanied by decrease in entropy, still it is a spontaneous process. Explain.

Ans. The molecules of adsorbate are held on the surface of adsorbent and therefore, they have lesser tendency to move freely. Therefore, its entropy decreases and ΔS is $-ve$, which opposes the process. However, adsorption is an exothermic process and therefore, ΔH is $-ve$. The magnitude of ΔH is more than $T\Delta S$ so that

$$\Delta G = \Delta H - T\Delta S = (-) - T(-)$$

$$\text{if } \Delta H > T\Delta S, \quad \Delta G = -ve$$

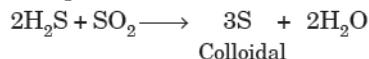
Therefore, there is decrease in free energy and hence, it is a spontaneous process.

Q.4. Why are medicines more effective in colloidal state?

Ans. A colloidal state has larger surface area of sol particles and therefore, are more effectively adsorbed. Therefore, the medicines in colloidal state are more easily assimilated or adsorbed and are more effective.

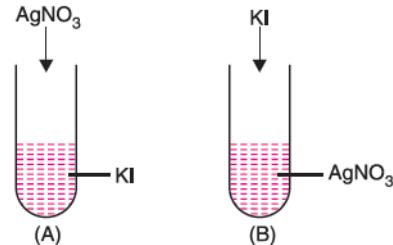
Q.5. On passing H_2S through an aqueous solution of SO_2 , a yellow turbidity is formed. Why?

Ans. On passing H_2S through an aqueous solution of SO_2 , oxidation of H_2S takes place.



The particles of sulphur formed get condensed to be in the colloidal range. Therefore, milky solution containing colloidal particles of sulphur is formed.

Q.6. A colloidal solution of AgI is prepared by two different methods as shown below :



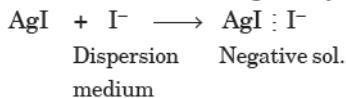
(i) What is the charge of colloidal particles in the two test tubes (A) and (B)?

(ii) Give reasons for the origin of charge.

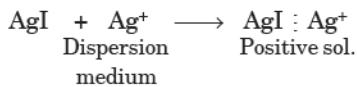
Ans. (i) (A) negative sol

(B) positive sol

(ii) The origin of charge is the selective adsorption of ions from the dispersion medium. The particles constituting the dispersed phase adsorb only those ions preferentially which are common with their own lattice ions. For example, if silver nitrate solution is added to an aqueous solution of potassium iodide, the silver iodide formed will adsorb negative I^- ions (common ions) from the dispersion medium to form a negatively charged sol.



However, if silver iodide is formed by adding potassium iodide to silver nitrate solution, the sol will be positively charged due to the adsorption of Ag^+ ions (common ions) present in the dispersion medium.



Q.7. Why does the sun looks red at the time of setting ? Explain on the basis of colloidal properties.

Ans. At the time of sun setting, the sun is at the horizon. The sun's rays have to travel a larger distance through the atmosphere. When the light emitted by the setting sun passes through the blanket of dust present in the atmosphere, the blue part of the light is scattered away by the dust particles and hence red part is visible.

Q.8. In an adsorption experiment, a graph between $\log\left(\frac{x}{m}\right)$ and $\log P$ was found to be linear with a slope

of 45° . The intercept on the $\log(x/m)$ axis was found to be 0.3010. Calculate the amount of the gas adsorbed per gram of the adsorbent under a pressure of 0.5 atmosphere.

Ans. According to Freundlich adsorption isotherm,

$$\frac{x}{m} = kp^{1/n}$$

$$\text{or } \log \frac{x}{m} = \log k + \frac{1}{n} \log P$$

Plot of $\log\left(\frac{x}{m}\right)$ vs $\log P$ is linear with slope $= \frac{1}{n}$ and

intercept $= \log k$. Thus,

$$\text{Slope} = \frac{1}{n} = \tan 45^\circ = 1$$

$$\therefore n = 1$$

$$\text{Intercept } \log k = 0.3010$$

$$\text{or } k = 2$$

$$\frac{x}{m} = kp^{1/n}$$

$$= 2 \times (0.5)^1 = 1.0$$

Q.9. 50 mL of 1M oxalic acid is shaken with 0.5 g of wood charcoal. The final concentration of the solution after adsorption is 0.6 M. Calculate the amount of oxalic acid adsorbed per gram of charcoal.

Ans. Amount of oxalic acid present can be calculated from the relation :

$$\text{Molarity} = \frac{w \times 1000}{M \times V(\text{in mL})}$$

$$\text{or } w = \frac{\text{Molarity} \times M \times V(\text{in mL})}{1000}$$

Amount of oxalic acid present initially

$$= \frac{1 \times 126 \times 50}{1000} = 6.3 \text{ g}$$

Amount of oxalic acid present after adsorption

$$= \frac{0.6 \times 126 \times 50}{1000} = 3.78 \text{ g}$$

$$\text{Amount adsorbed} = 6.3 - 3.78 = 2.52 \text{ g}$$

Amount adsorbed per gram of charcoal

$$= 2.52 \times 2 = 5.04 \text{ g}$$

Q.10. One gram of a water insoluble substance of density 0.8 g cm⁻³ is dispersed in 1L of water forming a colloidal solution having 10^{13} particles of spherical shape per mm³. Calculate the radius of the particle.

Ans. 1 mm³ of sol contains particles $= 10^{13}$

$$1 \text{ cm}^3 \text{ of sol contains particles} = 10^{13} \times 10^3 = 10^{16}$$

$$1 \text{ L of sol contain particles} = 10^{16} \times 10^3 \\ = 10^{19} \text{ particles}$$

$$\text{Mass of substance dispersed} = 1 \text{ g}$$

$$\text{Density} = 0.8 \text{ g cm}^{-3}$$

$$\text{Volume of dispersed substance} = \frac{1.0}{0.8} = 1.25 \text{ cm}^3$$

$$\text{Volume of 1 particle} = \frac{1.25}{10^{19}} = 1.25 \times 10^{-19} \text{ cm}^3$$

$$\text{Now } \text{Volume} = \frac{3}{4} \pi r^3 = 1.25 \times 10^{-19} \text{ cm}^3$$

$$r^3 = \frac{3}{4} \times 1.25 \times 10^{-19} \times \frac{7}{22}$$

$$= 29.8 \times 10^{-21} \text{ cm}^{-3}$$

$$r = (29.8 \times 10^{-21})^{1/3} = 3.1 \times 10^{-7} \text{ cm}$$

$$= 310 \times 10^{-9} \text{ m} = 310 \text{ nm}$$

Q.11. 20% surface sites have adsorbed N₂. On heating N₂ gas evolved from sites and was collected at 0.001 atm and 298 K in a container of volume 2.46 cm³. Density of the surrounding sites is $6.023 \times 10^{-14} \text{ cm}^{-2}$ and surface area is 1000 cm². Calculate the number of surface sites occupied per molecule of N₂.

(I.I.T. 2005)

Ans. Applying ideal gas equation

$$pV = nRT$$

$$\text{or } n = \frac{pV}{RT}$$

$$p = 0.001 \text{ atm},$$

$$V = 2.46 \text{ cm}^3 = 2.46 \times 10^{-3} \text{ L}$$

$$T = 298 \text{ K}$$

$$n = \frac{0.001 \times 2.46 \times 10^{-3}}{0.0821 \times 298} = 1 \times 10^{-7}$$

$$\text{No. of N}_2 \text{ molecules} = 6.023 \times 10^{23} \times 1 \times 10^{-7} = 6.023 \times 10^{16}$$

$$\text{Total sites available} = 6.023 \times 10^{14} \times 1000 = 6.023 \times 10^{17}$$

$$\text{Surface sites used to adsorb N}_2$$

$$= \frac{20}{100} \times 6.023 \times 10^{17}$$

$$= 12.04 \times 10^{16}$$

$$\therefore \text{Sites occupied per molecule of N}_2$$

$$\frac{\text{Surface sites used to adsorb N}_2}{\text{Molecules of N}_2} = \frac{12.04 \times 10^{16}}{6.023 \times 10^{16}} = 2$$



Revision Exercises

Very Short Answer Questions carrying 1 mark

1. Is adsorption exothermic or endothermic in nature ?
2. State Hardy Schulze rule. (H.P.S.B. 2018)
3. How is Brownian movement responsible for the stability of sols ? (C.B.S.E. Sample Paper 2017-18)
4. Does the adsorption of a gas on the surface of solid increases or decreases with rise in temperature ?
5. What causes Brownian movement in a colloidal solution ? (D.S.B. 2008)
6. What is adsorption isotherm? (Meghalaya S.B. 2017)
7. Write Freundlich adsorption isotherm equation at low pressure. (Pb.S.B. 2011)
8. Write Freundlich adsorption isotherm at intermediate pressure. (Pb.S.B. 2011)
9. What form will Freundlich adsorption isotherm equation take at high pressure ? (Pb. S.B. 2011, Uttarakhand S.B. 2012)
10. What is occlusion ? (Pb. S.B. 2012)
11. Name the type of emulsion to which milk belongs to. (Pb S.B. 2012, H.P.S.B 2012)
12. Name the type of emulsion to which butter belong to. (H.P.S.B. 2012)
13. Between absorption and adsorption, which one is surface phenomenon ? (Uttarakhand S.B. 2013)
14. Give one example each of lyophobic sol and lyophilic sol. (D.S.B. 2014)
15. Give one example each of sol and gel. (D.S.B. 2014)
16. Give one example each of 'oil in water' and 'water in oil' emulsion. (D.S.B. 2014)
17. Out of BaCl_2 and KCl which one is more effective in causing coagulation of negatively charged colloidal sol. Give reason. (D.S.B. 2015)
18. Write one similarity between physisorption and chemisorption. (D.S.B. 2017)
19. Which enzyme is used to convert glucose into ethyl alcohol? (H.P.S.B. 2017)
20. Define positive and negative catalysis. (Hr. S.B. 2017)
21. Give one example of a biochemical catalyst. (Assam S.B. 2017)
22. What are the dispersed phase and dispersion medium in soap lather? (W.B.S.B. 2018)

CBSE QUESTIONS

23. Which will be adsorbed more readily on the surface of charcoal and why : NH_3 or CO ? (A.I.S.B 2004)
24. Of physisorption and chemisorption, which type of adsorption has higher enthalpy of adsorption ? (A.I.S.B. 2008, D.S.B. 2008, A.I.S.B 2013)

25. Given an example of shape selective catalyst. (D.S.B. 2010, A.I.S.B. 2011)
26. What is the effect of temperature on chemisorption ? (A.I.S.B. 2014)
27. Why is adsorption always exothermic ? (A.I.S.B. 2014)
28. What are the dispersed phase and dispersion medium in milk ? (A.I.S.B. 2014)
29. Write a method by which lyophobic colloids can be coagulated. (A.I.S.B. 2015)
30. Write the main reason for the stability of colloidal sols. (D.S.B. 2016, A.I.S.B. 2016)
31. What type of colloid is formed when a solid is dispersed in liquid? Give an example. (A.I.S.B. 2017)
32. $\text{CO}(\text{g})$ and $\text{H}_2(\text{g})$ react to give different products in the presence of different catalysts. Which ability of the catalyst is shown by these reactions? (A.I.S.B. 2018)

MCQs from State Boards' Examinations

33. Movement of dispersion medium under the influence of electric field is known as

| | |
|---------------------|---------------------|
| (a) electrodialysis | (b) electrophoresis |
| (c) electroosmosis | (d) cataphoresis. |

 (H.P.S.B. 2013, Meghalaya S.B. 2016)
34. At CMC (Critical Micellization Conc.) the surface molecules

| | |
|--------------------------------|--|
| (a) associate | |
| (b) dissociate | |
| (c) decompose | |
| (d) become completely soluble. | |

 (H.P.S.B. 2013, Meghalaya S.B. 2016)
35. Milk is an example of

| | |
|--------------|-------------------------|
| (a) emulsion | (b) suspension |
| (c) foam | (d) sol. (Hr.S.B. 2013) |
36. Tyndall effect is due to

| | |
|-------------------------|-------------------------|
| (a) electric charge | (b) scattering of light |
| (c) absorption of light | (d) none of these. |

 (Hr.S.B. 2013)
37. Fog is a colloidal system of

| | |
|-------------------------------|-------------------------------|
| (a) liquid dispersed in a gas | (b) gas dispersed in a gas |
| (c) solid dispersed in gas | (d) solid dispersed in liquid |

 (Hr.S.B. 2013, Mizoram S.B. 2015, Nagaland S.B. 2018)
38. Blood may be purified by

| | |
|---------------------|----------------|
| (a) coagulation | (b) dialysis |
| (c) electro-osmosis | (d) filtration |

 (Hr.S.B. 2013, H.P.S.B. 2018)
39. Blue colour of water in sea is due to

| | |
|---|---------------------|
| (a) refraction of blue light by impurities in sea water | |
| (b) scattering of light by water | |
| (c) refraction of blue sky by water | |
| (d) None of these | (Mizoram S.B. 2014) |

- (ii) How will you justify that milk is an emulsion of oil in water with the help of dilution test ? (Pb.S.B. 2011)
- 12.** Explain the following:
- (i) Tyndall effect (Hr. S.B. 2011, 2018, H.P.S.B. 2015, Mizoram S.B. 2017)
 - (ii) Dialysis (Hr.S.B. 2011, Mizoram S.B. 2016, Assam S.B. 2016)
 - (iii) Electrophoresis (H.P.S.B. 2015, Assam 2016, Mizoram S.B. 2016)
 - (iv) Coagulation (H.P.S.B. 2015, Assam S.B. 2016, Mizoram S.B. 2017, Hr. S.B. 2018)
 - (v) Peptization (Mizoram S.B. 2016, Hr. S.B. 2018)
 - (vi) Emulsification (Assam S.B. 2016)
 - (vii) Brownian movement (Hr. S.B. 2018)
- 13.** What do you understand by activity and selectivity of catalysts ? (Hr.S.B. 2011, Nagaland S.B. 2017)
- 14.** Explain how the phenomenon of adsorption finds application in each of the following processes :
- (i) Production of vacuum
 - (ii) Heterogeneous catalysis
 - (ii) Froth floatation process.
- Or*
- Define each of the following terms :
- (i) Micelles (ii) Peptization (iii) Desorption (D.S.B. 2011)
- 15.** What is Tyndall effect ? Give its reasons and importance. (Pb. S.B. 2011, Hr. S.B. 2012, 2017, Uttarakhand. S.B. 2013, Jammu S.B. 2016)
- 16.** What is meant by coagulation of a colloidal solution ? Describe briefly any three methods by which coagulation of lyophobic sols can be carried out. (D.S.B. 2012)
- 17.** Describe a conspicuous change observed when
 - (i) a solution of NaCl is added to a sol of hydrated ferric oxide.
 - (ii) a beam of light is passed through a solution of NaCl and then through a sol. (D.S.B. 2012)
- 18.** Define enzyme catalysis. What is the reason for its specific action ? (Uttarakhand S.B. 2012)
- 19.** Differentiate between homogeneous and heterogeneous catalysis with one example of each. (Manipur S.B. 2012, Meghalaya S.B. 2016. Hr. S.B. 2018)
- 20.** Taking two examples of heterogeneous catalytic reactions, explain how a heterogeneous catalyst helps in the reaction. (Uttarakhand S.B. 2012)
- 21.** What are protective colloids ? How are the colloids stabilised? Explain the term gold number. (Chhattisgarh S.B. 2012)
- 22.** (a) Give two differences between macromolecular colloids and associated colloids.
- (b) Explain the term dialysis. How can it be increased? (Pb.S.B. 2018)
- 23.** What are associated colloids? How are they different from multimolecular and macromolecular colloids? (Meghalaya S.B. 2016)

- 24.** Write the dispersed phase and dispersion medium of the following colloidal systems:
 - (i) Smoke
 - (ii) Milk

Or

What are lyophilic and lyophobic colloids ? Which of these sols can be easily coagulated on the addition of small amounts of electrolytes ? (D.S.B. 2013)

25. What is the difference between oil/water (o/w) type and water/oil (w/o) type emulsions ? Given an example of each type. (D.S.B. 2013)

26. (a) What is adsorption isobar? Draw the adsorption isobar for physical adsorption and chemical adsorption. (Mizoram S.B. 2018)

(b) Give one example each of oil in water emulsion and water in oil emulsion. (Meghalaya S.B. 2018)

27. (a) Write any two differences between lyophilic and lyophobic colloids.

(b) What is heterogeneous catalysis? Give an example.

(c) Give an expression for Freundlich adsorption isotherm. (Karnataka S.B. 2018)

28. (a) What is Tyndall effect ?

(b) Define the following :

 - (i) Kraft temperature.
 - (ii) Critical micelles concentration.

(c) What happens when Fe(OH)_3 sol and As_2O_3 sol are mixed with each other ? (Meghalaya S.B. 2014)

29. (a) In reference to Freundlich adsorption isotherm write the expression for adsorption of gases on solids in the form of an equation.

(b) Write an important characteristic of lyophilic sols.

(c) Based on type of particles of dispersed phase, give one example each of associate colloid and multimolecular colloid. (D.S.B. 2014)

30. (a) Why does physisorption decrease with increase of temperature?

(b) Why are powdered substances more effective adsorbents than their crystalline forms?

(c) Give the decreasing order of flocculating power of the following ions in the coagulation of a negative sol. Na^+ , Ba^{2+} , Al^{3+} (Assam S.B. 2018)

31. (a) Describe briefly Brownian movement.

(b) Describe one method of purification of colloidal solution. (Hr.S.B. 2015)

32. (a) Explain the cleansing action of soaps.(Hr.S.B. 2015)

(b) Classify the type of colloidal sol in the following based on the basis of physical state:
smoke, milk, pumice stone, foam, rubber, cheese, gem stones. (Pb.S.B. 2015)

33. (a) State Hardy Schulze law.

(b) What are differences between physisorption and chemisorption. (Mention at least two differences).

(c) How does bleeding from a wound stop by applying alum? (Meghalaya S.B. 2015)

34. What are adsorption and absorption processes? Give one example to show the distinction between the two.

Or

Define homogeneous and heterogeneous catalysis. Give one suitable example of each of the two catalysis.

(Assam S.B. 2015, Hr. S.B. 2018)

35. Give reasons for the following observations:
 - (i) Leather gets hardened after tanning.
 - (ii) Lyophilic sol is more stable than lyophobic sol
 - (iii) It is necessary to remove CO when ammonia is prepared by Haber's process. (D.S.B. 2015)
36. Write any two features which distinguish between physisorption and chemisorption.
(Jharkhand S.B. 2016, Kolkata S.B. 2016)
37. Explain why the solid catalyst is used in a finely divided form as heterogeneous catalysis. (Kolkata S.B. 2016)
38. (i) Differentiate between adsorption and absorption.
(ii) Out of $MgCl_2$ and $AlCl_3$, which one is more effective in causing coagulation of negatively charged sol and why?
(iii) Out of sulphur sol and proteins, which one forms multimolecular colloids? (D.S.B. 2016)
39. (a) How will you differentiate between physical and chemical adsorption? Give at least four points of difference.
(b) Define gels. (H.P.S.B. 2017)
40. (a) Briefly explain Tyndall effect. Give its importance.
(b) Define adsorption. Give one example.
(Hr. S.B. 2017)
41. Define Tyndall effect. Differentiate between electrophoresis and electroosmosis. (Pb.S.B. 2017)
42. Define coagulation. Differentiate between physical adsorption and chemical adsorption. (Pb.S.B. 2017)
43. Define colloidal solution. Differentiate between lyophilic colloids and lyophobic colloids. (Pb.S.B. 2017)
44. (a) How do the size of particles of adsorbent and pressure of the gas influence the extent of adsorption?
(b) Define the following giving an example of each:
(i) Coagulation (ii) Tyndall effect.
(Manipur S.B. 2017)
45. Explain the following observations : (any three)
 - (i) Sky appears blue in colour.
 - (ii) Deltas are formed where river meets the sea.
 - (iii) Alum/ferric chloride solution is applied to stop bleeding.
 - (iv) Mist or fog is formed in winter. (Assam S.B. 2017)
46. (a) What is peptization? What is the cause of peptization?
(b) What happens when an electric field is applied to a colloidal solution? (Meghalaya S.B. 2017)
47. (a) Differentiate between physisorption and chemisorption.
(Hr. S.B. 2018)
(b) Write any two applications of adsorption.
(Kerala S.B. 2017)
48. Write one difference in each of the following:
 - (i) Lyophobic sol and lyophilic sol
 - (ii) Solution and colloid
 - (iii) Homogeneous catalysis and heterogeneous catalysis (D.S.B. 2017)
49. Write one difference between each of the following:
 - (i) Multimolecular colloid and macromolecular colloid
 - (ii) Sol and gel
 - (iii) O/W emulsion and W/O emulsion (D.S.B. 2017)
50. (i) Write the expression for Freundlich's equation to describe the behaviour of adsorption from solution.
(ii) What causes charge on sol particles?

(iii) Name the promoter used in the Haber's process for the manufacture of ammonia.

(C.B.S.E. Sample Paper 2017-18)

51. (a) Indicate a chemical reaction involving homogeneous catalyst.
(b) What is Brownian movement?
(c) Comment on the following statement : Colloid is not a substance but a state of substance. (Meghalaya S.B. 2018)
52. (a) State Hardy-Schulze rule with the help of example.
(b) Why are lyophilic colloids used as protective colloids? (Kerala S.B. 2018)

CBSE QUESTIONS

53. (a) In which of the following does adsorption take place and why ?
(i) Silica gel placed in the atmosphere saturated with water.
(ii) Anhydrous $CaCl_2$ placed in the atmosphere saturated with water.
(b) Give an example of shape selective catalysis.
(c) What are micelles? How do they differ from ordinary colloidal particles ? Give two examples of micelles forming substances. (A.I.S.B. 2006, H.P.S.B. 2011)
54. (a) How can colloidal solution and true solution of the same colour be distinguished from each other ?
(b) List four applications of adsorption.
Or
Explain the following observations :
(i) Lyophilic colloid is more stable than lyophobic colloid.
(ii) Coagulation takes place when sodium chloride solution is added to a colloidal solution of ferric hydroxide.
(iii) Sky appears blue in colour. (A.I.S.B. 2006)
55. Classify colloids where the dispersion medium is water. State their characteristics and write an example of each of these classes.
Or
Explain what is observed when
(i) an electric current is passed through a sol.
(ii) a beam of light is passed through a sol.
(iii) an electrolyte (say NaCl) is added to ferric hydroxide sol. (A.I.S.B., 2009, 2011, Assam S.B. 2012)
56. Write three distinct features of chemisorption which are not found in physisorption. (A.I.S.B. 2012)
57. What are the characteristics of the following colloids ? Give one example of each.
(i) Multimolecular colloids
(ii) Lyophobic sols
(iii) Emulsions (A.I.S.B. 2013)
58. Define the following terms giving an example of each :
(i) Associated colloids
(ii) Lyophilic sols
(iii) Adsorption (A.I.S.B. 2013)
59. Give reasons for the following observations:
(i) Physisorption decreases with increase in temperature.

- (ii) Addition of alum purifies the water.
 (iii) Brownian movement provides stability to the colloidal solution. (A.I.S.B. 2015)
- 60.** Define the following:
 (i) O/W Emulsion
 (ii) Zeta potential
 (iii) Multimolecular colloids (A.I.S.B. 2016)
- 61.** Write one difference in each of the following:
 (a) Multimolecular colloid and Associated colloid
 (b) Coagulation and Peptizaton
 (c) Homogeneous catalysis and Heterogeneous catalysis
Or
 (a) Write the dispersed phase and dispersion medium of milk.
 (b) Write one similarity between physisorption and chemisorption.
 (c) Write the chemical method by which Fe(OH)_3 sol is prepared from FeCl_3 . (A.I.S.B. 2017)
- 62.** What happens when
 (a) a freshly prepared precipitate of Fe(OH)_3 is shaken with a small amount of FeCl_3 solution?
 (b) persistent dialysis of a colloidal solution is carried out?
 (c) an emulsion is centrifuged? (A.I.S.B. 2018)

>> Long Answer Questions**carrying 5 marks**

- Define the terms physical adsorption and chemical adsorption and give any four points of differences between them.
- (a) What is catalyst ? How does the phenomenon of adsorption explain the role played by catalyst ?
 (b) What is electrophoresis ? What is its significance ?
Or
 (a) Discuss the phenomenon of dialysis and electrodialysis?
 (b) What are protective colloids ? (Pb. S.B. 2012)
- (a) What do you understand by activity and selectivity of a catalyst ? Give one example of each.
 (b) What is Tyndall effect ? What is its significance ?
Or
 (a) What is an emulsion ? Discuss the types of emulsions by giving example of each.
 (b) What do you mean by peptisation ? (Pb. S.B. 2012)
- (a) What is homogeneous and heterogeneous catalysis ? Give one example of each.
 (b) What is Brownian movement ? What is its cause ?
Or
 (a) What are multimolecular, macro molecular and associated colloids ? Give one example of each.
 (b) What do you mean by gold number ? (Pb. S.B. 2012)

Hints & Answers**for****Revision Exercises****Very Short Answer Questions**

- Exothermic
- Decreases with rise in temperature
- Chemisorption
- $\frac{x}{m} = kP$
- $\frac{x}{m} = kP^{1/n}$ (*n* is a whole number)
- $\frac{x}{m} = kP^0 = k$
- The adsorption of gases on the surface of metals is called occlusion.
- Oil-in-water type
- Water-in-oil type
- Adosorption is a surface phenomena
- Lyophobic : As_2S_3 , Lyophilic : Gelatin
- Sol : As_2S_3 , Gel : Gum arabic

- Oil in water : Milk, Water in Oil : Butter
- BaCl_2 because greater the valency of the coagulating ion (positive ion), greater is its tendency to coagulate.
- Invertase
- Gas and liquid
- NH_3
- Chemisorption
- Zeolites e.g., zeolite ZSM-5
- With increase in temperature, chemisorption first increases and then decreases.
- Because of attraction between adsorbate and adsorbent, energy is released during adsorption.
- Liquid (dispersed phase), Liquid (dispersion medium)
- By addition of electrolyte. 31. Gel, cheese
- Selectivity of a catalyst. It is the ability of a catalyst to selectively form a particular product.
- (b) 34. (a) 35. (a) 36. (b) 37. (a)
- (b) 39. (a) 40. (c) 41. (b) 42. (a)
- (c) 44. (d) 45. (b) 46. (a) 47. (b)
- (d) 49. (c) 50. (a) 51. (a) 52. (c)
- (c) 54. (c) 55. (d) 56. (c)

Competition File

Additional Useful Information and Objective Questions

ADDITIONAL USEFUL INFORMATION

- **ISOELECTRIC POINT OF COLLOIDS.** The H⁺ ions concentration at which the colloidal particles are neither positively charged nor negatively charged (*i.e.*, are electrically neutral) is known as **isoelectric point of a colloid**. For example, for gelatin, isoelectric point is at pH = 4.7. At this point the colloids do not migrate under the influence of electric field. At this point, the lyophilic colloids are expected to have **minimum stability**.

□ SYNERESIS AND THIOXOTROPY OF GELS

- When gels are allowed to stand for a long time, they give out small amount of trapped liquid which accumulates on its surface. This phenomenon is called **syneresis** or **weeping of gels**.
 - Some gels like gelation are semisolid when at rest and change to liquid sol. on agitation. This reversible sol. gel transformation is called **thixotropy**.

□ NANOMATERIALS

Nanomaterials are the materials having at least one

dimension less than 100 nm ($1 \text{ nm} = 10^{-9} \text{ m}$). These possess unique optical, conductance, magnetic, electrical and other properties which are different from those of their bulk counterparts because of their small particle size. These properties have great impact in electronics, medicines and other fields.

The common examples of nanomaterials are gold, carbon (fullerene), metals, metal oxides, metal alloys, etc. Due to their unique properties, the nanomaterials are gaining importance in different fields. These are widely used in a number of industrial processes as well as consumer products such as cosmetics, sun screens, stain resistant and wrinkle free textiles, electronics, paints and varnishes, etc. These are finding use as important constituents of mass media storage devices. These are also used as heterogeneous catalysts because they provide large surface area. In the field of biology and medicine, nanomaterials are used as Magnetic Resonance Imaging (MRI), contrast agents, etc.

OBJECTIVE TYPE QUESTIONS

Multiple Choice Questions

M. C. Q.

A *Topicwise* MULTIPLE CHOICE QUESTIONS with only one correct answer

Adsorption and Catalysis

(c) Adsorption is more for specific substance
(d) It is reversible reaction.

A5. According to adsorption theory of catalysis, the speed of the reaction increases because :

- (a) the concentration of the reactant molecules at the active centres of the catalyst becomes high due to adsorption.
- (b) in the process of adsorption, the activation energy of the molecules becomes large.
- (c) adsorption produces heat which increases the speed of the reaction.
- (d) adsorption lowers the activation energy of the reaction.

A6. Which of the following characteristics is not correct for physical adsorption ?

- (a) Adsorption increases with increase in temperature.
- (b) Adsorption is spontaneous.
- (c) Both enthalpy and entropy of adsorption are negative.

- (c) Both enthalpy and entropy of ad
(d) Adsorption on solid is reversible

A7. Rate of physisorption increases with
(a) decrease in temperature
(b) increase in temperature
(c) decrease in pressure
(d) decrease in surface area.

Answers

- A1: (b) A2: (b) A3: (d) A4: (a) A5: (d) A6: (a) A7: (a)

Competition File

- A8.** The volumes of gases H₂, CH₄, CO₂ and NH₃ adsorbed by 1 gm of activated charcoal at 298 K are in the order.
 (a) H₂ > CH₄ > CO₂ > NH₃
 (b) CH₄ > CO₂ > NH₃ > H₂
 (c) CO₂ > NH₃ > H₂ > CH₄
 (d) NH₃ > CO₂ > CH₄ > H₂
 (e) CO₂ > NH₃ > CH₄ > H₂
- A9.** Adsorption is accompanied by
 (a) decrease in enthalpy and increase in entropy
 (b) increase in enthalpy and increase in entropy
 (c) decrease in enthalpy and decrease in entropy
 (d) increase in enthalpy and decrease in entropy
- A10.** The enthalpy of physical adsorption is about
 (a) zero
 (b) 20-50 kJ mol⁻¹
 (c) 200-500 kJ mol⁻¹
 (d) very high

Colloids

- A11.** The colloidal system in which the disperse phase and dispersion medium are both liquids is known as
 (a) a gel
 (b) an aerosol
 (c) an emulsion
 (d) a foam.
- A12.** Freshly prepared precipitates can be easily dispersed by shaking it with dispersion medium. This process is called
 (a) Peptisation
 (b) Electrophoresis
 (c) Dispersion
 (d) Dialysis.
- A13.** The presence of electric charge on the colloidal particles is indicated by the experiment
 (a) Osmosis
 (b) Electrolysis
 (c) Dialysis
 (d) Electrophoresis.
- A14.** The number of phases in a colloidal system is
 (a) 1
 (b) 2
 (c) 3
 (d) 4.
- A15.** The process of separation of colloids by passing through semi-permeable membrane is called
 (a) Filtration
 (b) Electrophoresis
 (c) Dialysis
 (d) Ultrafiltration.
- A16.** The size of colloidal particles is in the range of
 (a) 0.1 – 1 nm
 (b) 1 nm – 100 nm
 (c) 100 nm – 1000 nm
 (d) 1000 – 10000 nm.
- A17.** An example of micelle is :
 (a) Sodium stearate
 (b) Gold sol.
 (c) Solution of NaCl
 (d) Ruby glass.
- A18.** Which of the following is most effective electrolyte in causing the flocculation of a negatively charged arsenious sulphide solution ?
 (a) KCl
 (b) MgCl₂
 (c) K₃Fe(CN)₆
 (d) AlCl₃
- A19.** Colloidal particles exhibit Tyndall effect due to
 (a) polarisation of light
 (b) scattering of light
 (c) reflection of light
 (d) refraction of light.

- A20.** Which of the following electrolytes will be most effective in causing the coagulation of a positively charged ferric hydroxide sol ?
 (a) K₂SO₄
 (b) K₃Fe(CN)₆
 (c) KCl
 (d) K₂CO₃.
- A21.** Soaps essentially form a colloidal solution in water and remove the greasy matter by
 (a) coagulation
 (b) emulsification
 (c) adsorption
 (d) absorption.
- A22.** Which of the following is an example of associated colloid?
 (a) Protein + Water
 (b) Soap + Water
 (c) Rubber + Benzene
 (d) As₂O₃ + Fe(OH)₃.
- A23.** Alums purify muddy water by
 (a) Dialysis
 (b) Adsorption
 (c) Coagulation
 (d) Forming a true solution.
- A24.** Which type of property is the Brownian movement of colloidal sol ?
 (a) Electrical
 (b) Optical
 (c) Mechanical
 (d) Colligative.
- A25.** When KI is added to silver nitrate solution, the sol formed may be written as :
 (a) AgI I⁻
 (b) AgI Ag⁺
 (c) AgI NO₃⁻
 (d) NO₃⁻ AgI Ag⁺.
- A26.** Which of the following reaction gives a colloidal sol ?
 (a) MgCO₃ → MgO + CO₂
 (b) 2Na + 2H₂O → 2NaOH + H₂
 (c) 2HNO₃ + 3H₂S → 3S + 4H₂O + 2NO
 (d) Cu + CuCl₂ → Cu₂Cl₂.
- A27.** Blue colour of water in sea is due to
 (a) refraction of blue light by impurities in sea water
 (b) scattering of light by water
 (c) refraction of blue sky by water
 (d) none of these.
- A28.** Alum helps in purifying water by
 (a) forming silicon complex with clay particles
 (b) sulphate part which combines with dirt and removes it
 (c) aluminium which coagulates the mud particles
 (d) making mud water soluble.
- A29.** The coagulating power of an electrolyte for arsenious sulphide sol decreases in the order :
 (a) Na⁺ > Al³⁺ > Ba²⁺
 (b) PO₄³⁻ > SO₄²⁻ > Cl⁻
 (c) Cl⁻ > SO₄²⁻ > PO₄³⁻
 (d) Al³⁺ > Ba²⁺ > Na⁺
 (e) Na⁺ > Ba²⁺ > PO₄³⁻
- A30.** The disease kala azar is cured by
 (a) colloidal antimony
 (b) milk of magnesia
 (c) argyrols
 (d) colloidal gold

Answers

- | | | | | | | | | | |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| A8. (d) | A9. (c) | A10. (b) | A11. (c) | A12. (a) | A13. (d) | A13. (d) | A14. (b) | A15. (c) | A16. (b) |
| A17. (a) | A18. (d) | A19. (b) | A20. (b) | A21. (b) | A22. (b) | A23. (c) | A24. (c) | A25. (b) | A26. (c) |
| A27. (a) | A28. (c) | A29. (d) | A30. (a) | | | | | | |

Competition File

MULTIPLE CHOICE QUESTIONS *from competitive examinations*

AIPMT & Other State Boards' Medical Entrance

Answers

- B1.** (b) **B2.** (c) **B3.** (d) **B4.** (b) **B5.** (a) **B6.** (d) **B7.** (b) **B8.** (c) **B9.** (c) **B10.** (c)
B11. (c) **B12.** (b) **B13.** (d) **B14.** (d) **B15.** (e)

Competition File

- B16.** Which one of the following is not explained by adsorption?
- When acetic acid solution is shaken with charcoal, the concentration of the acid decreases.
 - The white precipitate of $Mg(OH)_2$ attains blue colour when precipitated in the presence of magnesone reagent.
 - The air becomes dry in the presence of silica gel.
 - An aqueous solution of $NaOH$ attains pink colour with a drop of phenolphthalein.
 - When animal charcoal is shaken with coloured methylene blue solution, the solution turns colourless.
- (Kerala PMT 2014)*

- B17.** The correct ascending order of adsorption of the following gases on the same mass of charcoal at the same temperature and pressure is

- $CH_4 < H_2 < SO_2$
 - $H_2 < CH_4 < SO_2$
 - $SO_2 < CH_4 < H_2$
 - $H_2 < SO_2 < CH_4$
 - $CH_4 < SO_2 < H_2$
- (Kerala PMT 2015)*

- B18.** Which of the following statements is incorrect about physisorption?

- It is reversible in nature.
 - It forms multilayer.
 - It involves high activation energy.
 - The extent of physisorption decreases with increase of temperature.
 - It increases with increase in surface area.
- (Kerala PMT 2015)*

JEE (Main) & Other State Boards' Engineering Entrance

- B19.** Volume of a colloidal particle, V_c as compared to the volume of a solute particle in a true solution, V_s could be

- $\frac{V_c}{V_s} \approx 1$
 - $\frac{V_c}{V_s} \approx 1$
 - $\frac{V_c}{V_s} \approx 10^{-3}$
 - $\frac{V_c}{V_s} \approx 10^3$
- (A.I.E.E.E. 2005)*

- B20.** In Langmuir's model of adsorption of a gas on a solid surface.

- the adsorption at a single site on the surface may involve multiple molecules at the same time.
 - the mass of gas striking a given area of surface is proportional to the pressure of the gas.
 - the mass of gas striking a given area of surface is independent of the pressure of the gas.
 - the rate of dissociation of adsorbed molecules from the surface does not depend on the surface covered.
- (A.I.E.E.E. 2006)*

- B21.** Gold numbers of protective colloids A, B, C and D are 0.50, 0.01, 0.10 and 0.005 respectively. The correct order of their protective powers is

- $B < D < A < C$
- $D < A < C < B$
- $C < B < D < A$
- $A < C < B < D$

(A.I.E.E.E. 2008)

- B22.** Which of the following statements is incorrect regarding physisorption?

- It occurs because of van der Waals forces
- More easily liquefiable gases are adsorbed readily
- Under high pressure it results into multimolecular layer on adsorbent surface
- Enthalpy of adsorption is low and positive.

(A.I.E.E.E. 2009)

- B23.** According to Freundlich adsorption isotherm, which of the following is correct?

- $\frac{x}{m} \propto p^1$
- $\frac{x}{m} \propto p^{1/n}$
- $\frac{x}{m} \propto p^0$

- (d)** All the above are correct for different ranges of pressure.

(A.I.E.E.E. 2012)

- B24.** The coagulating power of electrolytes having ions Na^+ , Al^{3+} and Ba^{2+} for arsenic sulphide sol increases in the order

- $Al^{3+} < Na^+ < Ba^{2+}$
- $Al^{3+} < Ba^{2+} < Na^+$
- $Na^+ < Ba^{2+} < Al^{3+}$
- $Ba^{2+} < Na^+ < Al^{3+}$

(JEE. Main. 2013)

- B25.** 3g of activated charcoal was added to 50 mL of acetic acid solution (0.06 N) in a flask. After an hour it was filtered and the strength of the filtrate was found to be 0.042 N. The amount of acetic acid adsorbed (per gram of charcoal) is

- 42 mg
- 54 mg
- 18 mg
- 36 mg

(JEE. Main 2015)

- B26.** For a linear plot of $\log(x/m)$ versus $\log P$ in a Freundlich adsorption isotherm, which of the following statement is correct? (k and n are constants).

- both k and $1/n$ appear in the slope term.
- $1/n$ appears as the intercept.
- Only $1/n$ appears as the slope.
- $\log(1/n)$ appears as the intercept.

(JEE Main 2016)

- B27.** Tyndall effect is observed only when following conditions are satisfied:

- The diameter of the dispersed particles is much smaller than the wavelength of the light used.
- The diameter of the dispersed particle is not much smaller than the wavelength of the light used.
- The refractive indices of the dispersed phase and dispersion medium are almost similar in magnitude.
- The refractive indices of the dispersed phase and dispersion medium differ greatly in magnitude.

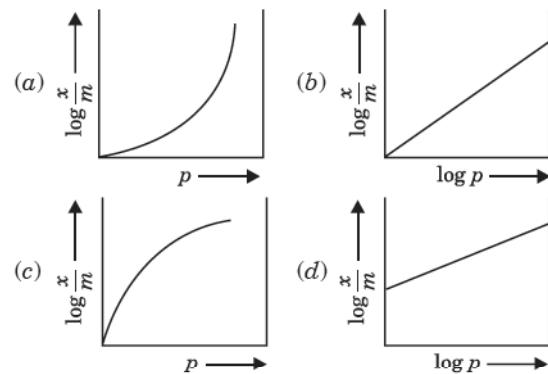
- (A) and (C)
- (B) and (C)
- (A) and (D)
- (B) and (D)

(JEE. Main 2017)

Answers

- | | | | |
|-----------------|-----------------|-----------------|-----------------|
| B16. (d) | B17. (b) | B18. (c) | B19. (d) |
| B20. (b) | B21. (d) | B22. (d) | B23. (d) |
| B24. (c) | B25. (c) | B26. (c) | B27. (d) |

Competition File



(Karnataka CET 2015)

Answers

B28. (d) **B29.** (d) **B30.** (c) **B31.** (a) **B32.** (c) **B33.** (c) **B33.** (c) **B35.** (a) **B36.** (c) **B37.** (d)
B38. (e) **B39.** (c) **B40.** (d) **B41.** (b) **B42.** (d)

Competition File

- B43.** Enzymatic reactions are given in Column I and enzymes in Column II

| <i>Column I</i> | <i>Column II</i> |
|---|------------------|
| (A) Maltose → Glucose | (i) Zymase |
| (B) Sucrose → Glucose + Fructose | (ii) Pepsin |
| (C) Glucose → Ethyl alcohol + CO ₂ | (iii) Maltase |
| (D) Starch → Maltose | (iv) Invertase |
| (E) Proteins → Amino acids | (v) Diastase |

Choose the correct matching of enzymatic reaction and enzyme that catalyses the correct reaction from the codes given below:

- (a) (A) – (ii), (B) – (iv), (C) – (v), (D) – (iii), (E) – (i)
- (b) (A) – (iii), (B) – (iv), (C) – (i), (D) – (v), (E) – (ii)
- (c) (A) – (v), (B) – (iv), (C) – (ii), (D) – (i), (E) – (iii)
- (d) (A) – (v), (B) – (iii), (C) – (iv), (D) – (ii), (E) – (i)
- (e) (A) – (ii), (B) – (iii), (C) – (i), (D) – (v), (E) – (iv)

(Kerala PET 2016)

- B44.** In which one of the following properties, physisorption and chemisorption resemble each other?

- (a) Force of attraction (b) Enthalpy of adsorption
- (c) Temperature effect (d) Effect of surface area
- (e) Number of adsorption layers (Kerala PET 2016)

- B45.** Which of the following statement is incorrect w.r.t. physisorption?

- (a) The forces involved are van der Waals forces.
- (b) More easily liquefiable gases are adsorbed easily.
- (c) Under high pressure it results into multimolecular layer on adsorbent surface.
- (d) $\Delta H_{\text{adsorption}}$ is low and +ve (WB JEE 2016)

- B46.** Reactions in zeolite catalyst depend on

- (a) pores (b) apertures
- (c) size of cavity (d) all of these.

(Karnataka C.E.T. 2016)

- B47.** Which of the following is not a favourable condition for physical adsorption?

- (a) High pressure (b) Low temperature
- (c) High temperature (d) Higher critical temperature of adsorbate

(Karnataka CET 2017)

- B48.** The process which is responsible for the formation of delta at a place where rivers meet the sea is

- (a) peptization (b) colloidal formation
- (c) emulsification (d) coagulation

(Karnataka CET 2017)

- B49.** Which of the statement is true regarding chemisorption of a gas on a solid surface?

- (a) This type adsorption first increases with increase of temperature
- (b) No compound formation takes place in this case

- (c) The forces operating in this are weak van der Waals' forces

- (d) It forms multimolecular layers of gas molecules on the surface (J.K. CET 2018)

- B50.** Which of the following is the correct increasing order of coagulating power of electrolytes required to precipitate a negatively charged As₂S₃ colloid?

- (a) NaCl < BaCl₂ < AlCl₃
- (b) BaCl₂ < AlCl₃ < NaCl
- (c) AlCl₃ < NaCl < BaCl₂
- (d) AlCl₃ < BaCl₂ < NaCl (J.K. CET 2018)

- B51.** Which of the following electrolyte will have maximum coagulating value for AgI/Ag⁺ sol?

- (a) Na₂S (b) Na₃PO₄
- (c) Na₂SO₄ (d) NaCl (Karnataka CET 2018)

- B52.** Gold sol is not a

- (a) lyophobic sol (b) negatively charged sol
- (c) macromolecular sol (d) multimolecular colloid (Karnataka CET 2018)

- B53.** Which of the following statement is true about the adsorption?

- (a) $\Delta H < 0$ and $\Delta S < 0$ (b) $\Delta H > 0$ and $\Delta S < 0$
- (c) $\Delta H < 0$ and $\Delta S > 0$ (d) $\Delta H = 0$ and $\Delta S < 0$
- (e) $\Delta H = 0$ and $\Delta S > 0$ (Kerala PET 2018)

JEE (Advance) for IIT Entrance

- B54.** Lyophilic sols are

- (a) reversible sols
- (b) they are prepared from inorganic compound
- (c) coagulated by adding electrolytes
- (d) self stabilizing (I.I.T. 2005)

- B55.** Among the following, the surfactant that will form micelles in aqueous solution at the lowest molar concentration at ambient conditions is

- (a) CH₃(CH₂)₁₅N⁺(CH₃)₃Br⁻
- (b) CH₃(CH₂)₁₁OSO₃⁻Na⁺
- (c) CH₃(CH₂)₆COO⁻Na⁺
- (d) CH₃(CH₂)₁₁N⁺(CH₃)₃Br⁻ (I.I.T 2008)

- B56.** Among the electrolytes Na₂SO₄, CaCl₂, Al₂(SO₄)₃ and NH₄Cl, the most effective coagulating agent for Sb₂S₃ sol is

- (a) Na₂SO₄ (b) CaCl₂
- (c) Al₂(SO₄)₃ (d) NH₄Cl (IIT-JEE 2009)

- B57.** Methylene blue, from its aqueous solution, is adsorbed on activated charcoal at 25°C. For this process, the correct statement is

- (a) the adsorption requires activation at 25°C.
- (b) the adsorption is accompanied by a decrease in enthalpy.
- (c) the adsorption increases with increase of temperature.
- (d) the adsorption is irreversible. (JEE Advance 2013)

Answers

- B43.** (b) **B44.** (d) **B45.** (d) **B46.** (d) **B47.** (c)
B53. (a) **B54.** (d) **B55.** (a) **B56.** (c) **B57.** (b)

- B48.** (d) **B49.** (a) **B50.** (a) **B51.** (d) **B52.** (c)

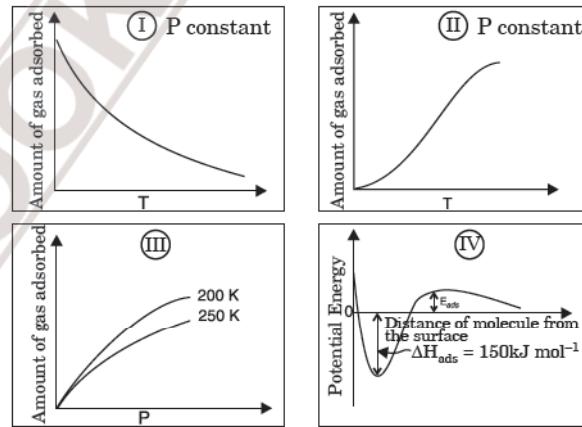
Competition File

C MULTIPLE CHOICE QUESTIONS with more than one correct answers

- C1.** Which of the following increases the activation of a solid adsorbent ?
 (a) subdividing the solid adsorbent
 (b) carrying out adsorption at very elevated temperature
 (c) blowing superheated steam through porous adsorbent
 (d) polishing the surface of solid adsorbent
- C2.** Which of the following statements are correct ?
 (a) The protective power of a colloid may be measured by reciprocal of gold number.
 (b) A gel is a colloidal system in which a solid is dispersed in a liquid.
 (c) For positively charged sol, the coagulating power of coagulating ion decreases as : $\text{PO}_4^{3-} > \text{SO}_4^{2-} > \text{Cl}^-$
 (d) In colloids, the particles constituting the dispersed phase adsorb only those ions preferentially which are opposite with the own lattice ions.
- C3.** The macromolecular colloids
 (a) consist of aggregates of atom or molecules which generally have diameter less than 1nm.
 (b) have usually lyophobic character
 (c) have molecules which are flexible and can take any shape
 (d) have molecules containing both lyophilic and lyophobic groups.
- C4.** Which of the following is/are not true in Langmuir adsorption isotherm ?
 (a) At high pressure, $\frac{x}{m} = kP$
 (b) Plot of $\log(x/m)$ and $\log P$ is a straight line
 (c) At low pressure, $\frac{x}{m} = kP$
 (d) in intermediate range of pressure, $\frac{x}{m} = kP^{1/n}$
 (n = whole number)
- C5.** Which of the following statements are not correct ?
 (a) A catalyst does not change ΔH of a reaction.
 (b) The enzymes are highly specific in nature.
 (c) Generally, very large quantities of enzyme catalysts are required to increase the rates of reaction.
 (d) Oxidation of alcohol to acetic acid can be carried out by invertase enzyme.
- C6.** The correct statement(s) pertaining to the adsorption of a gas on a solid surface is (are)
 (a) Adsorption is always exothermic
 (b) Physisorption may transform into chemisorption at high temperature
 (c) Physisorption increases with increasing temperature but chemisorption decreases with increasing temperature.
 (d) Chemisorption is more exothermic than physisorption, however it is very slow due to higher energy of activation. (I.I.T. 2011)

- C7.** Choose the correct reason(s) for the stability of the lyophobic colloidal particles.
 (a) Preferential adsorption of ions on their surface from the solution.
 (b) Preferential adsorption of solvent on their surface from the solution.
 (c) Attraction between different particles having opposite charges on their surface.
 (d) Potential difference between the fixed layer and the diffused layer of opposite charges around the colloidal particles. (I.I.T. J.E.E. 2012)

- C8.** The given graphs/data I, II, III and IV represent general trends observed for different physisorption and chemisorption processes under mild conditions of temperature and pressure. Which of the following choice(s) about I, II, III and IV is(are) correct ?



- (a) I is physisorption and II is chemisorption
 (b) I is physisorption and III is chemisorption
 (c) IV is chemisorption and II is chemisorption
 (d) IV is chemisorption and III is chemisorption (I.I.T.J.E.E. 2012)

- C9.** When O_2 is adsorbed on a metallic surface, electron transfer occurs from the metal to O_2 . The TRUE statement(s) regarding this adsorption is (are)
 (a) O_2 is physisorbed
 (b) heat is released
 (c) occupancy of π_{2p}^* of O_2 is increased
 (d) bond length of O_2 is increased. (JEE Advance 2015)
- C10.** The correct statement(s) about surface properties is (are)
 (a) cloud is an emulsion type of colloid in which liquid is dispersed phase and gas is dispersion medium.
 (b) the critical temperatures of ethane and nitrogen are 563 K and 126 K, respectively. The adsorption of ethane will be more than that of nitrogen on same amount of activated charcoal at a given temperature.
 (c) adsorption is accompanied by decrease in enthalpy and decrease in entropy of the system.
 (d) Brownian motion of colloidal particles does not depend on the size of the particles but depends on viscosity of the solution. (JEE Advance 2017)

Answers

- C1.** (a, c) **C2.** (a, c) **C3.** (b, c) **C4.** (b, d) **C5.** (c, d) **C6.** (a, b, d) **C7.** (a, d) **C8.** (a, c) **C9.** (b, c, d) **C10.** (b, c)

Competition File

D MULTIPLE CHOICE QUESTIONS based on the given passage/comprehension

Passage I

Thomas Graham in 1861, during his work on diffusion found that certain substances such as gelatin, albumin, glue, etc. diffused at very slow rate and were called colloids. The colloid particles have the size in the range of 1 to 100 nm consisting of dispersed phase and dispersion medium. The dispersed phase or dispersion medium may be solid, liquid or even a gas. Depending upon the nature of dispersion medium or dispersed phase, 8 types of systems are possible except for a gas dispersed in another gas because the gases are completely miscible with each other. The substances which have strong interaction with the dispersion medium are called lyophilic colloids while those which do not pass into colloidal state readily are called lyophobic colloids. Lyophobic sols are much less stable and are irreversible.

particles of dispersed phase gets neutralised and precipitation takes place. This process is also called coagulation. The coagulation is given by Hardy Schulze rules. According to these rules the ions carrying the charge opposite to that of sol particles are effective and coagulating power of an electrolyte is directly proportional to the fourth power of the valency of the ion. Coagulation can also occur by mutual precipitation, by electrophoresis, by persistent dialysis or by heating or cooling.

Answer the following questions :

D1. The size of colloidal particles is

- (a) less than those of true solution
- (b) more than those of suspension
- (c) in the range 10 pm to 10^6 pm
- (d) in the range 10 \AA to 1000 \AA (J&K C.E.T. 2006)

D2. Which of the following statements is not correct ?

- (a) Lyophobic sols can be easily prepared only by mixing.
- (b) Lyophilic sols are stable and irreversible.
- (c) Lyophobic sols are unstable and are not reversible
- (d) The particles of lyophobic sol are heavily solvated

D3. Which of the following is not true about lyophilic sols ?

- (a) They are stable
- (b) They are reversible
- (c) They are heavily hydrated or solvated
- (d) They are not easily formed by direct mixing

Passage II

The particles of colloidal solution possess electrical charge which is responsible for the stability of these solutions. The charge on colloidal particles arises because of selective adsorption of ions which are common with their own lattice. The presence of charge on colloidal particles can be determined with the help of a phenomenon known as electrophoresis. However, when some electrolyte is added, the charge on the

Answer the following questions :

D4. The charge of colloidal particles can be determined by the phenomenon

- (a) electrodialysis
- (b) electrophoresis
- (c) Bredig's arc method
- (d) electro-osmosis

D5. The flocculation values of NaCl and AlCl_3 are 51 and 0.093 millimoles/litre for arsenic sulphide sol. This means that

- (a) AlCl_3 has 51 times more coagulating power than NaCl
- (b) NaCl has 548 times more coagulating power than AlCl_3
- (c) AlCl_3 has 548 times more coagulating power than NaCl
- (d) The ratio of coagulating power of $\text{AlCl}_3 : \text{NaCl}$ is 51 : 0.093

D6. Which of the following electrolyte is most effective for coagulating Fe(OH)_3 sol ?

- (a) $\text{K}_3[\text{Fe}(\text{CN})_6]$
- (b) $\text{Na}_2\text{C}_2\text{O}_4$
- (c) K_2SO_4
- (d) KCl

D7. The stability of colloidal solution is due to

- (a) size of colloidal particles
- (b) charge of colloidal particles
- (c) movement of colloidal particles under applied electric field
- (d) tendency to show Tyndall effect.

D8. Which of the following electrolyte requires maximum concentration to cause coagulation of As_2S_3 sol ?

- (a) AlCl_3
- (b) MgSO_4
- (c) $\text{K}_3[\text{Fe}(\text{CN})_6]$
- (d) KCl

Answers

Passage I.

D1. (d)

D2. (c)

D3. (d)

Passage II.

D4. (b)

D5. (c)

D6. (a)

D7. (b)

D8. (d)

Competition File

Assertion Reason Type Questions

The questions given below consist of an Assertion and the Reason. Use the following key to choose the appropriate answer.

- (a) If both assertion and reason are CORRECT and reason is the correct explanation of the assertion.
 - (b) If both assertion and reason are CORRECT, but reason is NOT THE CORRECT explanation of the assertion.
 - (c) If assertion is CORRECT but reason is INCORRECT.
 - (d) If assertion is INCORRECT but reason is CORRECT.
 - (e) If both assertion and reason are INCORRECT.
- 1. Assertion :** Physical adsorption of molecules on the surface requires activation energy.
Reason : Because the bonds of adsorbed molecules are broken.
- 2. Assertion :** Activity of an enzyme is pH dependent.
Reason : Changes in pH affects the solubility of the enzyme in water. (A.I.I.M.S. 2003)

3. **Assertion :** Small quantity of soap is required to prepare a stable emulsion.
Reason : Soaps lowers the interfacial tension between oil and water.
4. **Assertion :** Sea water looks blue.
Reason : Due to scattering of light by colloidal impurities present in sea water.
5. **Assertion :** For a negatively charged sol., the coagulation value of NaCl and MgCl₂ are 52.0 and 0.72 respectively.
Reason : Greater charge of cation causes slower coagulation.
6. **Assertion :** The micelle formed by sodium stearate in water has – COO⁻ groups at the surface.
Reason : Surface tension of water is reduced by addition of stearate. (A.I.I.M.S. 2003)
7. **Assertion :** The conversion of fresh precipitate to colloidal state is called peptization.
Reason : It is caused by addition of common ions. (A.I.I.M.S. 2007)

Answers

1. (e) 2. (b) 3. (a) 4. (a) 5. (c) 6. (a) 7. (b)

Matrix Match Type Questions

Each question contains statements given in two columns, which have to be matched. Statements in Column I are labelled as A, B, C and D whereas statements in Column II are labelled as p, q, r and s. Match the entries of Column I with appropriate entries of Column II. Each entry in Column I may have one or more than one correct option from Column II. The answers to these questions have to be appropriately bubbled as illustrated in the following example.

If the correct matches are A-q, A-r, B-p, B-s, C-r, C-s and D-q, then the correctly bubbled matrix will look like the following:

| | p | q | r | s |
|---|----------------------------------|----------------------------------|-----------------------|----------------------------------|
| A | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| B | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| C | <input type="radio"/> | <input checked="" type="radio"/> | <input type="radio"/> | <input checked="" type="radio"/> |
| D | <input checked="" type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

1. Match the example given in Column I with the type of colloid given in Column II.

| Column I | Column II |
|-------------------|--|
| (A) Whipped cream | (p) Emulsion |
| (B) Medicines | (q) Sol |
| (C) Cell fluids | (r) Colloids having gas as dispersion phase |
| (D) Foam | (s) Colloids having liquid dispersion medium |

2. Match the entries of Column I with appropriate entries in Column II.

| Column I | Column II |
|------------------------|---|
| (A) Lyophobic colloids | (p) liquid fats dispersed in water |
| (B) Lyophilic colloids | (q) behave as normal electrolyte at low concentration and colloidal at high concentration |
| (C) Micelles | (r) get coagulated by electrolytes |
| (D) Emulsions | (s) show Tyndall effect. |

3. Match the column I with type of colloid given in column II

| Column I | Column II |
|-----------------|--------------------|
| (A) Starch sol | (p) Associated |
| (B) Soap sol | (q) Multimolecular |
| (C) Gelatin sol | (r) Macromolecular |
| (D) Gold sol | (s) Lyophilic |

Answers

- | | | | |
|----------------------|----------------|----------------|-----------|
| (1) : (A) – (s) | (B) – (p), (s) | (C) – (q), (s) | (D) – (r) |
| (2) : (A) – (r), (s) | (B) – (r) | (C) – (q) | (D) – (p) |
| (3) : (A) – (r), (s) | (B) – (p) | (C) – (r), (s) | (D) – (q) |

Competition File

Matching List Type Questions

Each question has matching lists. The codes for the lists have choices (a), (b), (c) and (d), out of which ONLY ONE is correct.

- Match list I with list II and select the correct answer using the code :

| List I (Type of colloid) | List II (Example) |
|--------------------------|-------------------|
| P. Liquid in solid | 1. Hair cream |
| Q. Gas in liquid | 2. Cheese |
| R. Liquid in liquid | 3. Fog |
| S. Liquid in gas | 4. Whipped cream |

| | P | Q | R | S |
|-----|---|---|---|---|
| (a) | 2 | 1 | 3 | 4 |
| (b) | 1 | 3 | 2 | 4 |

Answers

1. (c) 2. (d)



NCERT

Multiple Choice Questions (Type-I)

- Which of the following process does *not* occur at the interface of phases ?
 - crystallisation
 - heterogenous catalysis
 - homogeneous catalysis
 - corrosion
- At the equilibrium position in the process of adsorption _____.
 - $\Delta H > 0$
 - $\Delta H = T \Delta S$
 - $\Delta H > T \Delta S$
 - $\Delta H < T \Delta S$
- Which of the following interface cannot be obtained ?
 - liquid-liquid
 - solid-liquid
 - liquid-gas
 - gas-gas
- The term 'sorption' stands for _____.
 - absorption
 - adsorption
 - both absorption and adsorption
 - desorption
- Extent of physisorption of a gas increases with _____.
 - increase in temperature.

Answers

1. (c) 2. (b) 3. (d) 4. (c) 5. (b) 6. (a) 7. (a) 8. (d)

| | | | | |
|-----|---|---|---|---|
| (c) | 2 | 4 | 1 | 3 |
| (d) | 1 | 4 | 2 | 3 |

- Match list I of enzymatic reaction with enzyme given in list II :

| List I | List II |
|--|------------------|
| P. Proteins \rightarrow Amino acid | 1. Zymase |
| Q. Glucose \rightarrow Ethyl alcohol + CO_2 | 2. Lacto bacilli |
| R. Starch \rightarrow Maltose | 3. Pepsin |
| S. Milk \rightarrow Curd | 4. Diastase |

| | P | Q | R | S |
|-----|---|---|---|---|
| (a) | 3 | 4 | 1 | 2 |
| (b) | 4 | 1 | 3 | 2 |
| (c) | 3 | 4 | 2 | 1 |
| (d) | 3 | 1 | 4 | 2 |

Exemplar Problems

Objective Questions

- decrease in temperature.
- decrease in surface area of adsorbent.
- decrease in strength of van der Waals forces.
- Extent of adsorption of adsorbate from solution phase increases with _____.
 - increase in amount of adsorbate in solution.
 - decrease in surface area of adsorbent.
 - increase in temperature of solution.
 - decrease in amount of adsorbate in solution.
- Which one of the following is not applicable to the phenomenon of adsorption ?

| | |
|----------------|----------------|
| $\Delta H > 0$ | $\Delta G < 0$ |
| $\Delta S < 0$ | $\Delta H < 0$ |
- Which of the following is not a favourable condition for physical adsorption ?
 - high pressure
 - negative ΔH
 - higher critical temperature of adsorbate
 - high temperature

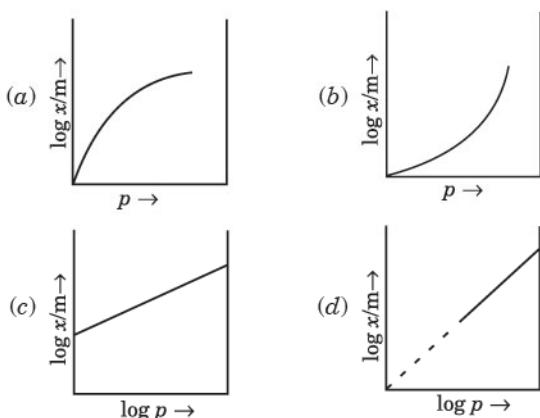
9. Physical adsorption of a gaseous species may change to chemical adsorption with _____.
 (a) decrease in temperature
 (b) increase in temperature
 (c) increase in surface area of adsorbent
 (d) decrease in surface area of adsorbent
10. In physisorption, adsorbent does not show specificity for any particular gas because _____.
 (a) involved van der Waals forces are universal.
 (b) gases involved behave like ideal gases.
 (c) enthalpy of adsorption is low.
 (d) it is a reversible process.
11. Which of the following is an example of absorption ?
 (a) Water on silica gel
 (b) Water on calcium chloride
 (c) Hydrogen on finely divided nickel
 (d) Oxygen on metal surface
12. On the basis of data given below predict which of the following gases shows least adsorption on a definite amount of charcoal ?
- | | | | | |
|------------------|-----------------|-----------------|-----------------|----------------|
| Gas | CO ₂ | SO ₂ | CH ₄ | H ₂ |
| Critical temp./K | 304 | 630 | 190 | 33 |
- (a) CO₂ (b) SO₂ (c) CH₄ (d) H₂
13. In which of the following reactions heterogenous catalysis is involved ?
- $2\text{SO}_2(g) + \text{O}_2(g) \xrightarrow{\text{NO}(g)} 2\text{SO}_3(g)$
 - $2\text{SO}_2(g) \xrightarrow{\text{Pt}(s)} 2\text{SO}_3(g)$
 - $\text{N}_2(g) + 3\text{H}_2(g) \xrightarrow{\text{Fe}(s)} 2\text{NH}_3(g)$
 - $\text{CH}_3\text{COOCH}_3(l) + \text{H}_2\text{O}(l) \xrightarrow{\text{HCl}(l)}$
 $\text{CH}_3\text{COOH}(aq) + \text{CH}_3\text{OH}(aq)$
- (a) (ii), (iii) (b) (ii), (iii), (iv)
 (c) (i), (ii), (iii) (d) (iv)
14. At high concentration of soap in water, soap behaves as _____.
 (a) molecular colloid (b) associated colloid
 (c) macromolecular colloid
 (d) lyophilic colloid
15. Which of the following will show Tyndall effect ?
 (a) Aqueous solution of soap below critical micelle concentration.
 (b) Aqueous solution of soap above critical micelle concentration.
 (c) Aqueous solution of sodium chloride.
 (d) Aqueous solution of sugar.
16. Method by which lyophobic sol can be protected.
 (a) By addition of oppositely charged sol.
 (b) By addition of an electrolyte.
 (c) By addition of lyophilic sol.
 (d) By boiling.
17. Freshly prepared precipitate sometimes gets converted to colloidal solution by _____.
 (a) coagulation (b) electrolysis
 (c) diffusion (d) peptisation
18. Which of the following electrolytes will have maximum coagulating value for AgI/Ag⁺ sol ?
 (a) Na₂S (b) Na₃PO₄
 (c) Na₂SO₄ (d) NaCl
19. A colloidal system having a solid substance as a dispersed phase and a liquid as a dispersion medium is classified as _____.
 (a) solid sol (b) gel
 (c) emulsion (d) sol
20. The values of colligative properties of colloidal solution are of small order in comparison to those shown by true solutions of same concentration because of colloidal particles _____.
 (a) exhibit enormous surface area.
 (b) remain suspended in the dispersion medium.
 (c) form lyophilic colloids.
 (d) are comparatively less in number.
21. Arrange the following diagrams in correct sequence of steps involved in the mechanism of catalysis, in accordance with modern adsorption theory.
- (i)
- (ii)
- (iii)
- (iv)
- (v)
- (a) i → ii → iii → iv → v
 (b) i → iii → ii → iv → v
 (c) i → iii → ii → v → iv
 (d) i → ii → iii → v → iv

Answers

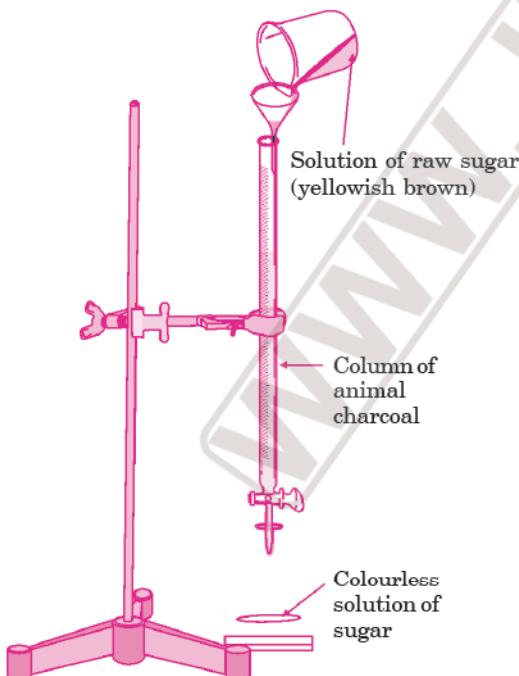
9. (b) 10. (a) 11. (b) 12. (d) 13. (a) 14. (b) 15. (b) 16. (c) 17. (d)
 18. (b) 19. (d) 20. (d) 21. (b)

Competition File

22. Which of the following process is responsible for the formation of delta at a place where rivers meet the sea ?
 (a) Emulsification (b) Colloid formation
 (c) Coagulation (d) Peptisation
23. Which of the following curves is in accordance with Freundlich adsorption isotherm ?



24. Which of the following process is not responsible for the presence of electric charge on the sol particles ?
 (a) Electron capture by sol particles.
 (b) Adsorption of ionic species from solution.
 (c) Formation of Helmholtz electrical double layer.
 (d) Absorption of ionic species from solution.
25. Which of the following phenomenon is applicable to the process shown in the figure ?



- (a) Absorption (b) Adsorption
 (c) Coagulation (d) Emulsification

Multiple Choice Questions (Type-II)

Note : In the following questions two or more options may be correct.

26. Which of the following options are correct ?
 (a) Micelle formation by soap in aqueous solution is possible at all temperatures.
 (b) Micelle formation by soap in aqueous solution occurs above a particular concentration.
 (c) On dilution of soap solution micelles may revert to individual ions.
 (d) Soap solution behaves as a normal strong electrolyte at all concentrations.
27. Which of the following statements are correct about solid catalyst ?
 (a) Same reactants may give different product by using different catalysts.
 (b) Catalyst does not change ΔH of reaction.
 (c) Catalyst is required in large quantities to catalyse reactions.
 (d) Catalytic activity of a solid catalyst does not depend upon the strength of chemisorption.
28. Freundlich adsorption isotherm is given by the expression $\frac{x}{m} = kP^n$, which of the following conclusions can be drawn from this expression.
 (a) When $\frac{1}{n} = 0$, the adsorption is independent of pressure.
 (b) When $\frac{1}{n} = 0$, the adsorption is directly proportional to pressure.
 (c) When $n = 0, \frac{x}{m}$ vs P graph is a line parallel to x -axis.
 (d) When $n = 0$, plot of $\frac{x}{m}$ vs P is a curve.
29. H_2 gas is adsorbed on activated charcoal to a very little extent in comparison to easily liquefiable gases due to _____.
 (a) very strong van der Waals interaction.
 (b) very weak van der Waals forces.
 (c) very low critical temperature.
 (d) very high critical temperature.
30. Which of the following statements are correct ?
 (a) Mixing two oppositely charged sols neutralises their charges and stabilises the colloid.
 (b) Presence of equal and similar charges on colloidal particles provides stability to the colloids.
 (c) Any amount of dispersed liquid can be added to emulsion without destabilising it.
 (d) Brownian movement stabilises sols.

Answers

22. (c) 23. (c) 24. (d) 25. (b) 26. (b, c) 27. (a, b) 28. (a, c) 29. (b, c) 30. (b, d)

Competition File

- 31.** An emulsion cannot be broken by _____ and _____.
- heating
 - adding more amount of dispersion medium
 - freezing
 - adding emulsifying agent
- 32.** Which of the following substances will precipitate the negatively charged emulsions?
- | | |
|----------|-------------|
| (a) KCl | (b) Glucose |
| (c) Urea | (d) NaCl |
- 33.** Which of the following colloids cannot be coagulated easily?
- Lyophobic colloids.
 - Irreversible colloids.
 - Reversible colloids.
 - Lyophilic colloids.
- 34.** What happens when a lyophilic sol is added to a lyophobic sol?
- Lyophobic sol is protected.
 - Lyophilic sol is protected.
- 35.** Film of lyophilic sol is formed over lyophobic sol.
- 36.** Film of lyophobic sol is formed over lyophilic sol.
- 37.** Which phenomenon occurs when an electric field is applied to a colloidal solution and electrophoresis is prevented?
- Reverse osmosis takes place.
 - Electroosmosis takes place.
 - Dispersion medium begins to move.
 - Dispersion medium becomes stationary.
- 38.** In a reaction, catalyst changes _____.
- physically
 - qualitatively
 - chemically
 - quantitatively
- 39.** Which of the following phenomenon occurs when a chalk stick is dipped in ink?
- adsorption of coloured substance
 - adsorption of solvent
 - absorption and adsorption both of solvent
 - absorption of solvent

Answers

31. (b, d) **32.** (a, d) **33.** (c, d) **34.** (a, c) **35.** (b, c) **36.** (a, b) **37.** (a, d)

Matching Type Questions

Note : Match the items of Column I and Column II in the following questions.

- 38.** Method of formation of solution is given in Column I. Match it with the type of solution given in Column II.

| <i>Column I</i> | <i>Column II</i> |
|--|---------------------------------|
| (a) Sulphur vapours passed through cold water | (i) Normal electrolyte solution |
| (b) Soap mixed with water above critical micelle concentration | (ii) Molecular colloids |
| (c) White of egg whipped with water | (iii) Associated colloid |
| (d) Soap mixed with water below critical micelle concentration | (iv) Macromolecular colloids |

- 39.** Match the statement given in Column I with the phenomenon given in Column II.

| <i>Column I</i> | <i>Column II</i> |
|---|----------------------|
| (a) Dispersion medium moves in an electric field | (i) Osmosis |
| (b) Solvent molecules pass through semipermeable membrane towards solvent side | (ii) Electrophoresis |
| (c) Movement of charged colloidal particles under the influence of applied electric potential towards oppositely charged electrodes | (iii) Electroosmosis |
| (d) Solvent molecules pass through semipermeable membranes towards solution side | (iv) Reverse osmosis |

Answers

38. (a) — (ii) ; (b) — (iii) ; (c) — (iv) ; (d) — (i) **39.** (a) — (iii) ; (b) — (iv) ; (c) — (ii) ; (d) — (i)

Competition File

40. Match the items given in Column I and Column II.

| <i>Column I</i> | <i>Column II</i> |
|----------------------------------|--|
| (i) Protective colloid | (a) $\text{FeCl}_3 + \text{NaOH}$ |
| (ii) Liquid - liquid colloid | (b) Lyophilic colloids |
| (iii) Positively charged colloid | (c) Emulsion |
| (iv) Negatively charged colloid | (d) $\text{FeCl}_3 + \text{hot water}$ |

41. Match the types of colloidal systems given in Column I with the name given in Column II.

| <i>Column I</i> | <i>Column II</i> |
|----------------------|------------------|
| (a) Solid in liquid | (i) Foam |
| (b) Liquid in solid | (ii) Sol |
| (c) Liquid in liquid | (iii) Gel |
| (d) Gas in liquid | (iv) Emulsion |

42. Match the items of Column I and Column II.

| <i>Column I</i> | <i>Column II</i> |
|---------------------|-------------------------------|
| (a) Dialysis | (i) Cleansing action of soap |
| (b) Peptisation | (ii) Coagulation |
| (c) Emulsification | (iii) Colloidal sol formation |
| (d) Electrophoresis | (iv) Purification |

43. Match the items of Column I and Column II.

| <i>Column I</i> | <i>Column II</i> |
|------------------|-------------------------------------|
| (a) Butter | (i) dispersion of liquid in liquid |
| (b) Pumice stone | (ii) dispersion of solid in liquid |
| (c) Milk | (iii) dispersion of solid in liquid |
| (d) Paints | (iv) dispersion of liquid in solid |

Answers

40. (a) — (ii) ; (b) — (iii) ; (c) — (iv) ; (d) — (i)

42. (a) — (iv) ; (b) — (iii) ; (c) — (i) ; (d) — (ii)

41. (a) — (ii) ; (b) — (iii) ; (c) — (iv) ; (d) — (i)

43. (a) — (iv) ; (b) — (iii) ; (c) — (i) ; (d) — (ii)

Assertion and Reason Type Questions

Note : In the following questions a statement of assertion followed by a statement of reason is given. Choose the correct answer out of the following choices.

(a) Assertion and reason both are correct and the reason is correct explanation of assertion.

(b) Assertion and reason both are correct but reason does not explain assertion.

(c) Assertion is correct but reason is incorrect.

(d) Both assertion and reason are incorrect.

(e) Assertion is incorrect but reason is correct.

44. **Assertion :** An ordinary filter paper impregnated with collodion solution stops the flow of colloidal particles.

Reason : Pore size of the filter paper becomes more than the size of colloidal particle.

45. **Assertion :** Colloidal solutions show colligative properties.

Reason: Colloidal particles are large in size.

46. **Assertion :** Colloidal solutions do not show brownian motion.

Reason : Brownian motion is responsible for stability of sols.

47. **Assertion :** Coagulation power of Al^{3+} is more than Na^+ .

Reason : Greater the valency of the flocculating ion added, greater is its power to cause precipitation (Hardy Schulze rule).

48. **Assertion :** Detergents with low CMC are more economical to use.

Reason : Cleansing action of detergents involves the formation of micelles. These are formed when the concentration of detergents becomes equal to CMC.

Answers

44. (c)

45. (b)

46. (e)

47. (a)

48. (a)

Competition File

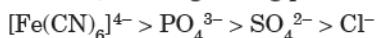
Hints & Explanations for Difficult Objective Type Questions

A. mcq with only one correct answer

- A1.** (b) : Physical adsorption may be multilayer.
- A3.** (d) : $\frac{x}{m} = kP^{1/n}$ or $\log \frac{x}{m} = \log k + \frac{1}{n} \log P$
Plot of $\log x/m$ vs $\log P$ will be a straight line with
slope = $\frac{1}{n}$.
- A4.** (a) : On increasing temperature adsorption decreases continuously in physical adsorption and firstly increases and then decreases in case of chemisorption.
- A18.** (d) : Cation having maximum positive charge i.e., Al^{3+} .
- A25.** (b) : AgI : Ag^+ because AgNO_3 is present in excess.
- A28.** (c) : Alum helps in purifying water by Al^{3+} ions which coagulate the negative mud particles.
- A29.** (d) : As_2S_3 is a negative sol and therefore coagulating power decreases as $\text{Al}^{3+} > \text{Ba}^{2+} > \text{Na}^+$

B. mcq from Competitive Examinations

- B1.** (b) : When a graph is plotted between $\log x/m$ and $\log p$, for Langmuir adsorption, a straight line is obtained with a slope = $1/n$. The equation of straight line is $\log x/m = \log K + 1/n \log p$.
- B3.** (d) : $\frac{x}{m} = p \times T$ is incorrect.
- B5.** (a) : Freundlich adsorption isotherm is $\frac{x}{m} = kp^{1/n}$ where n is > 1 so that $(1/n)$ lies between 0 and 1.
- B6.** (d) : The rate of enzyme activity rises rapidly with temperature and becomes maximum at a definite temperature called the optimum temperature. On either side of the optimum temperature, the enzyme activity decreases.
- B10.** (c) : Lower is the coagulation value, higher is the coagulation power. Therefore, coagulating power is in the order : III (MgSO_4) $>$ II (BaCl_2) $>$ I (NaCl)
- B11.** (c) : According to Hardy Schulze rule, the coagulating power of an ion depends upon magnitude and sign of the coagulating ion.
- B12.** (b) : The given sol is positively charged because the colloidal particles move towards cathode. Its coagulation can be caused by oppositely charged anion. Therefore, the coagulating power is :



B15. (e) :

$$\frac{x}{m} = kp^{1/n}$$

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

$$\text{Slope} = \frac{1}{n} = 0$$

Thus, $\frac{x}{m} = kp^0$

B17. (b) : Higher the critical temperature of a gas, greater is the amount of gas adsorbed. The critical temperature of $\text{H}_2 < \text{CH}_4 < \text{SO}_2$. Therefore, the order of adsorption will be $\text{H}_2 < \text{CH}_4 < \text{SO}_2$.

B18. (c) : It has very low activation energy.

B19. (d) : For a true solution, the diameter range is 1 to $< 10 \text{ \AA}$, and for colloidal solution, diameter range is $10 - 1000 \text{ \AA}$. Taking lower limits,

$$\frac{V_c}{V_s} = \frac{\frac{4}{3}\pi r_c^3}{\frac{4}{3}\pi r_s^3} = \left(\frac{r_c}{r_s}\right)^3$$

$$r_c = \frac{10}{2} = 5 \text{ \AA}, \quad r_s = \frac{1}{2} = 0.5 \text{ \AA}$$

$$\frac{V_c}{V_s} = \left(\frac{5}{0.5}\right)^3 = \frac{10^3}{1}$$

B20. (b) : In Langmuir adsorption, the rate of condensation depends upon the pressure of the gas as according to kinetic theory, the number of molecules striking per unit area is proportional to the pressure of the gas.

B21. (d) : Lesser the gold number of a protective colloid, better is its protective power.
 $A < C < B < D$

B22. (d) : For physisorption, ΔH is negative.

B23. (d) : According to Freundlich adsorption isotherm : $\frac{x}{m} = kP^{1/n}$
 $1/n$ can have values between 0 to 1 over different ranges of pressure.

B24. (c) : As_2S_3 is a negatively charged sol. Therefore, coagulating power is proportional to the valency of the active (positive) ion (Hardy Schulze rule)
 $\therefore \text{Al}^{3+} > \text{Ba}^{2+} > \text{Na}^+ \text{ or } \text{Na}^+ < \text{Ba}^{2+} < \text{Al}^{3+}$

B25. (c) : Moles of acetic acid initially present = $\frac{0.06 \times 50}{1000} = 3.0 \times 10^{-3}$

Moles of acetic acid after adsorption = $\frac{0.042 \times 50}{1000} = 2.1 \times 10^{-3}$

Moles of acetic acid adsorbed = $3.0 \times 10^{-3} - 2.1 \times 10^{-3} = 0.9 \times 10^{-3}$ moles

Mass of acetic acid adsorbed = $0.9 \times 10^{-3} \times 60 = 54 \times 10^{-3} \text{ g}$

Amount of acetic acid adsorbed per gram of charcoal

$$= \frac{54 \times 10^{-3}}{3} = 18 \times 10^{-3} \text{ g} = 18 \text{ mg}$$

B26. (c) : According to Freundlich adsorption isotherm,

$$\frac{x}{m} = kP^{\frac{1}{n}}$$

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

Competition File

- Plot of $\log(x/m)$ vs $\log P$ gives intercept = $\log k$ and slope = $\frac{1}{n}$. Therefore, only $\frac{1}{n}$ appears as the slope.
- B27. (d)** : The conditions (B) and (D) are correct.
- B28. (d)** : Amount of starch in milligram added to 10 mL of gold sol required to prevent coagulation of 1 mL of 10% NaCl solution = 0.25 g or = 250 mg.
Amount of starch required to be added to 10 mL of gold sol. to completely prevent coagulation of 1 mL of 10% NaCl solution.
- $$\frac{250}{100} \times 10 = 25 \text{ mg}$$
- Hence, gold number = 25
- B29. (d)** : On addition of KI to AgNO_3 , AgI is formed. Since KI is added in excess, the AgI formed adsorbs K^+ and I^- which form the Helmholtz electrical double layer.
- B30. (c)** : Electrodialysis is used to remove electrolytes. Urea is a non-electrolyte.
- B32. (c)** : Fe(OH)_3 is a positive sol. and therefore, the best coagulant is PO_4^{3-} ion.
- B39. (c)** : $\log \frac{x}{m} = \log k + \frac{1}{n} \log P$
Intercept = $\log k$, slope = $\frac{1}{n}$
- B40. (d)** : Macromolecular colloids are quite stable and resemble true solution in many respects. Therefore these cannot be easily coagulated.
- B41. (b)** : $\text{Ag}|\text{Ag}^+$ is a positively charged sol. It can be coagulated by a negative ion. For its flocculation, PO_4^{3-} ions have maximum flocculation power and Cl^- ions have minimum flocculation power. Hence, NaCl will have maximum flocculation value.
- B42. (d)** : Freundlich adsorption isotherm is
- $$\frac{x}{m} = k P^{1/n}$$
- or $\log \frac{x}{m} = \log k + \frac{1}{n} \log P$
- Hence plot of $\log \frac{x}{m}$ vs $\log P$ will be straight line with intercept equal to $\log k$ (not zero as in (b))
- B44. (d)** : Both physisorption and chemisorption increase with increase in surface area.
- B45. (d)** : In physisorption, $\Delta H_{\text{adsorption}}$ is low and always negative.
- B50. (a)** : The coagulating power of an electrolyte depends upon the charge on the oppositely charged ion of the electrolyte. For negatively charged sol, the order is : $\text{Na}^+ < \text{Ba}^{2+} < \text{Al}^{3+}$
- B51. (b)** : AgI/Ag^+ is positively charged sol and, therefore, negative ion will cause coagulation. The coagulation value decreases with increase in charge of the coagulating ion. Since Cl^- ion has minimum charge, it will have maximum coagulation value.
- B53. (a)** : Adsorption is accompanied by evolution of heat ($\Delta H < 0$) and decrease in randomness ($\Delta S < 0$).

- B54. (d)** : Lyophilic sols are self stabilizing because these sols are reversible and are highly hydrated in the solution.
- B56. (c)** : Sb_2S_3 is a negatively charged sol. Hence $\text{Al}_2(\text{SO}_4)_3$ is the most effective coagulating agent because higher the magnitude of opposite charge (Al^{3+}), higher is the coagulating power.
- B57. (b)** : The adsorption of methylene blue on activated charcoal is physical adsorption. It is accompanied by a decrease in enthalpy.

C. mcq with more than one correct answer

- C8. (a, c)** : In physisorption on increasing temperature at constant pressure, adsorption decreases while in chemisorption, adsorption will increase due to requirement of activation energy for adsorption at the same pressure. So, I is physisorption and II is chemisorption.
III is physisorption because on increasing temperature, extent of adsorption decreases. Graph IV represents enthalpy change during chemisorption (due to bond formation). So, IV is for chemisorption. Hence correct answer is (a,c)
- C10. (b, c)** : (b) Higher the critical temperature, higher will be the extent of adsorption.
(c) For adsorption, $\Delta H = -ve$ (exothermic) and $\Delta S = -ve$ (decrease in entropy)

NCERT Exemplar Problems : MCQs Type-I

- 1. (c)** : There is no interface in homogeneous catalysis.
- 2. (b)** : At equilibrium position during adsorption, $\Delta G = \Delta H - T\Delta S = 0$ so that $\Delta H = T\Delta S$.
- 3. (d)** : Gas-gas interface is not possible because gases are miscible.
- 7. (a)** : $\Delta H > 0$ is not possible.
- 8. (d)** : Because physical adsorption decreases with increase in temperature.
- 12. (d)** : Higher the critical temperature, large is the adsorption. With decrease in critical temperature, adsorption decreases.
- 17. (d)** : Peptisation is a process of converting freshly prepared precipitate to a colloidal solution.
- 18. (b)** : Because it contains highly charged precipitating ion (PO_4^{3-}).
- 22. (c)** : Delta is formed due to coagulation of electrolytes present in sea water.

NCERT Exemplar Problems : MCQs Type-II

- 28. (a, c)** : When $\frac{1}{n} = 0$, $\frac{x}{m} = k$ i.e., adsorption is independent of pressure.
When $n = 0$, $\frac{x}{m}$ vs P graph becomes parallel to x -axis
- 32. (a, d)** : because these contain positively charged coagulating ions.
- 36. (a, b)** : A catalyst is recovered unchanged after the reaction and therefore it changes only physically and qualitatively.

