B.Sc. (Honours) Part-I
Paper-IA
Topic: Processes at Solid Surface
UG
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13.1 INTRODUCTION

There are several examples which reveal the fact that the surface of a solid (or liquid) has a tendency to attract and retain the molecules of other immiscible phase with which it is brought into contact. These molecules remain only at the surface and do not go deeper into the bulk. **This tendency of accumulation of molecular species at the surface than in the bulk of a solid (or liquid) is termed adsorption.** The molecular species or substance which concentrates or accumulates at the surface is termed **adsorbate** and the material on whose surface the adsorption has taken place is called **adsorbent**.

Adsorption is essentially a **surface phenomenon** and solids, particularly in finely divided state, have large surface area and, therefore, show this property to a much larger extent than liquids. Charcoal, silica gel, alumina gel, clay, Fuller's earth, colloids, metals in finely divided state, etc., act as good **adsorbents**.

The adsorption of gases on metal surfaces is called occlusion.

Examples of Adsorption

(i) If a gas like Cl_2, NH_3 or SO_2 is enclosed in presence of powdered charcoal in a closed vessel, 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.

(ii) In a solution of an organic dye say methylene blue, when animal charcoal is added and the solution is well shaken, it is found that the filtrate obtained after filtration is colourless. The molecules of the dye, thus, concentrate on the surface of charcoal, *i.e.*, solute molecules from solution are adsorbed.

(iii) Water solution of raw sugar, when passed over beds of animal charcoal, becomes colourless as the colouring substances are adsorbed by animal charcoal.

(iv) The air becomes dry, *i.e.*, loses moisture in presence of silica gel. Molecules of water concentrate on the surface of gel, *i.e.*, are adsorbed.

It is clear from the above examples that solid surfaces can hold the gas molecules, liquid molecules and also solid molecules by virtue of adsorption. **The process of removing an adsorbed substance from a surface on which it is adsorbed is called desorption.**

13.2 DISTINCTION BETWEEN ADSORPTION AND ABSORPTION

There are two similar sounding terms adsorption and absorption. Both the terms have different meanings. In adsorption, the substance is concentrated only at the surface and does not penetrate through the surface to go deep inside the bulk of the adsorbent, while in absorption, the substance is uniformly distributed throughout the bulk of the solid or liquid. For example, when a chalk stick is dipped in ink, the surface attains the colour of the ink due to adsorption of coloured molecules while the solvent of the ink goes deeper into the stick due to absorption. On breaking the chalk stick it is found that it is white from inside. Water vapours are absorbed by anhydrous calcium chloride while these are adsorbed by silica gel. **In other words, in adsorption the concentration of the adsorbate increases only at the surface of the adsorbent, while in absorption the concentration is uniform throughout the bulk of the solid.**

Both adsorption and absorption take place simultaneously. **Mc Bain** introduced a general term **sorption** to describe both the

Note: Rate of adsorption is high at the beginning and then decreases till equilibrium is attained. On the other hand, rate of absorption remains same throughout the process.
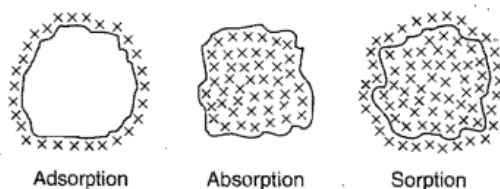
| Adsorption | Absorption | Sorption |

Fig. 13.1

processes. However, adsorption is instantaneous, *i.e.*, a fast process while absorption is a slow process, *e.g.*,

(i) If silica gel is placed in a vessel containing water vapours, the latter are adsorbed on the former. On the other hand, if anhydrous $CaCl_2$ is kept in place of silica gel, absorption takes place as the water vapours are uniformly distributed in $CaCl_2$ to form hydrated calcium chloride ($CaCl_2 \cdot 2H_2O$).

(ii) Dyes get adsorbed as well as absorbed in the cotton fibres, *i.e.*, sorption takes place.

13.3 MECHANISM OF ADSORPTION

Adsorption is due to the fact that the surface particles of the adsorbent are in different state than the particles inside the bulk. Inside the adsorbent all the forces acting between the particles are mutually balanced but on the surface the particles are not surrounded by atoms or molecules of their kind on all sides and hence they possess unbalanced or residual attractive forces. These forces of the adsorbent are responsible for attracting the adsorbate particles on its surface.

The extent of adsorption increases with the increase of surface area per unit mass of the adsorbent at a given temperature and pressure. This shows that with increase of surface area, the unbalanced attractive forces of the surface are also increased.

Another important factor regarding adsorption is the **heat of 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. **Adsorption, therefore, is invariably accompanied by evolution of heat**, *i.e.*, it is an exothermic process. In other words, ΔH of adsorption is always negative. When a gas is adsorbed, the freedom of movement of its molecules becomes restricted. This amounts to decrease in the entropy of the gas after adsorption, *i.e.*, ΔS is negative. **Adsorption is thus accompanied by decrease in enthalpy as well as decrease in entropy of the system.** For a process to be instantaneous, the thermodynamic requirement is that ΔG must be negative, *i.e.*, there is decrease in free energy. On the basis of equation, $\Delta G = \Delta H - T\Delta S$, ΔG can be negative if ΔH has sufficiently high negative value as $-T\Delta S$ is positive.

Thus, in an adsorption process, which is spontaneous,

ΔS is negative,

ΔH is also sufficiently negative,

and as a combination of these two factors,

ΔG is negative.

ΔH becomes less and less negative as adsorption proceeds further and further. Ultimately ΔH becomes equal to $T\Delta S$ and ΔG becomes zero. This is the state at which equilibrium is attained.

13.4 TYPES OF ADSORPTION (Adsorption of Gases)

There are two main types of adsorption of gases on solids.

If accumulation of gas on the surface of a solid occurs on account of weak van der Waals' forces, the adsorption is termed as physical adsorption or physisorption. When the gas molecules or atoms are held to the solid surface by chemical bonds, the adsorption is termed **chemical adsorption** or **chemisorption.** The chemical bonds may be covalent or ionic in nature. Chemisorption has a rather high energy of activation and is, therefore, often referred to as **activated adsorption.** Sometimes these two processes occur simultaneously and it is not easy to ascertain the type of adsorption. A physical adsorption at low temperature may pass into chemisorption as the temperature is increased. For example, hydrogen is first adsorbed on nickel by van der Waals' forces. Molecules of hydrogen then dissociate and hydrogen atoms are held on the surface by chemisorption.

Some of the important characteristics of both types of adsorption are described below:

1. Characteristics of physical adsorption

(i) Lack of specificity: The surface of an adsorbent does not show very strong attraction for a particular gas as the van der Waals' forces are universal.

(ii) Nature of gas: The amount of gas adsorbed by a solid depends on the nature of gas. In general, more easily liquefiable gases (*i.e.*, higher critical temperatures) are readily adsorbed as van der Waals' forces are stronger near the critical temperatures. Thus, 1g of activated charcoal adsorbs 380 mL of sulphur dioxide (critical temp. 157° C), 16 mL of methane (critical temp. −83° C) and 4.5 mL of hydrogen (critical temp. −240° C).

Gas	H_2	N_2	CO	CH_4	CO_2	HCl	NH_3	SO_2
Volume adsorbed (c.c.)	4.5	8	9.3	16.2	48	72	181	380
Critical temperature (K)	33	126	134	190	304	324	406	430

(iii) Reversible nature: Physical adsorption of a gas by a solid is generally reversible. The gas adsorbed can be removed by reversing the conditions of temperature and pressure. Thus,

$$\text{Gas} \rightleftharpoons \text{Gas/Solid} + \text{Heat}$$

More of gas is adsorbed when pressure is increased as the volume of the gas decreases (Le-Chatelier's principle) and it can be removed by decreasing pressure.

Since, the adsorption process is exothermic, the physical adsorption occurs readily at low temperature and decreases with increasing temperature (Le-Chatelier's principle). As the activation energy in the physical adsorption is more or less zero, the rate of adsorption is not affected even at low temperature.

(iv) Surface area of adsorbent: The extent of adsorption increases with increase of surface area of the adsorbent. Thus, finely divided metals and porous substances having large surface areas are good adsorbents.

(v) Heat of adsorption: No doubt, physical adsorption is an exothermic process but its heat of adsorption is quite low

(20 – 40 kJ mol^{-1} or about 5 kcal mol^{-1}) since the attraction between gas molecules and solid surface is due to weak van der Waals' forces.

2. Characteristics of chemisorption

(i) High specificity: Chemisorption is highly specific and it will only occur if there is some possibility of chemical bonding. For example, oxygen is adsorbed on metals by virtue of oxide formation and hydrogen is adsorbed by transition metals with unpaired d-orbitals leading to hydride formation.

(ii) Nature of gas: Chemisorption will occur if there is some possibility of chemical action between the gas and the solid adsorbent.

(iii) Irreversibility: As chemisorption involves compound formation, it is commonly irreversible in nature. Chemisorption is also an exothermic process but the process is very slow at low temperature on account of high energy of activation. Like most chemical changes, it often increases with rise of temperature. A gas adsorbed at low temperature by physical adsorption may change into chemisorption at high temperature.

High pressure is favourable for chemisorption.

(iv) Surface area: Like physical adsorption, chemisorption also increases with increase of surface area of the adsorbent.

(v) Heat of adsorption: Heat of adsorption is high enough (40–400 kJ/mol) as chemisorption involves bond formation.

Comparison of physisorption and chemisorption

Physical adsorption	Chemical adsorption
1. It is caused by intermolecular van der Waals' forces.	It is caused by chemical bond formation.
2. It is not specific.	It is highly specific.
3. It is reversible.	It is irreversible.
4. It depends on the nature of gas. More easily liquefiable gases are adsorbed readily.	It depends on the nature of gas. Gases which form compounds with the adsorbent exhibit chemisorption.
5. Heat of adsorption is low.	Heat of adsorption is high.
6. Low temperature is favourable. It decreases with increase of temperature.	High temperature is favourable. It increases with increase of temperature.
7. No appreciable activation energy is involved.	High activation energy is involved.
8. High pressure is favourable. Decrease of pressure causes desorption.	High pressure is favourable. Decrease of pressure does not cause desorption.
9. It depends on the surface area. It increases with increase of surface area.	It also depends on the surface area. It increases with increase of surface area.
10. It forms multilayers on adsorbent surface under high pressure.	It forms unimolecular layer.

Adsorption of N$_2$ on the Surface of Iron

Nature of adsorption of nitrogen on the surface of iron depends on the temperature. At 83 K, nitrogen is physisorbed on iron surface as N$_2$ molecules. The degree of adsorption decreases rapidly as the temperature increases. At room temperature, there is no adsorption of N$_2$ on iron. When temperature is further increased up to 773 K and above, then nitrogen is chemisorbed on the iron surface as nitrogen atom.

Activation of Adsorption

Adsorbing power of an adsorbent can be increased by a number of ways. Some important methods are described below:

(i) Metallic adsorbents are activated by rubbing the surface.

(ii) Activity of adsorbent can be increased by taking it in powdered state because in the powdered state the surface area is maximum.

(iii) Adsorbing power of adsorbent can be increased by heating with superheated steam. For example, the charcoal is activated by heating between 650 K and 1330 K in vacuum, air or superheated steam.

13.5 ADSORPTION ISOTHERMS

The variation of the amount of the gas adsorbed by the adsorbent with pressure at constant temperature can be expressed by means of a curve. This curve is termed as **adsorption isotherm** at the particular temperature.

Freundlich adsorption isotherm: Freundlich, in 1909, gave an empirical relationship between the quantity of gas adsorbed by unit mass of solid adsorbent and pressure at a particular temperature. The relationship can be expressed by the following equation:
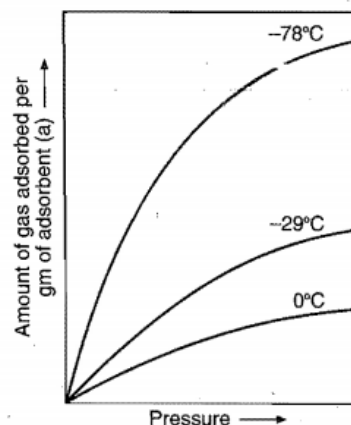

Fig. 13.2 Adsorption isotherm

$$\frac{x}{m} = k \cdot P^{1/n} \qquad \ldots (i)$$

where 'x' is the mass of the gas adsorbed on a mass 'm' of the adsorbent at a pressure P. k and n are constants which depend on the nature of the adsorbent and the gas at a particular temperature. The relationship is generally represented in the form of a curve when mass of the gas adsorbed per gram of the adsorbent is

plotted against the pressure (Fig. 13.2). These curves indicate that at a fixed pressure, there is decrease in physical adsorption with increase in temperature. These curves always seem to approach saturation at high pressure.

Taking logarithm of equation (i),

$$\log \frac{x}{m} = \log k + \frac{1}{n} \log P \qquad \ldots \text{(ii)}$$

This is the equation of a straight line. The validity of Freundlich isotherm can be verified by plotting $\log \frac{x}{m}$ on y-axis (ordinate) and $\log P$ on x-axis (abscissa). If it comes to be a straight line, the Freundlich isotherm is valid, otherwise not [Fig. 13.3(a)]. The slope of the straight line gives the value of $1/n$.
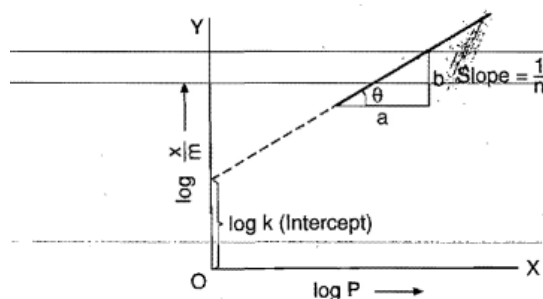

Fig. 13.3 (a) Freundlich isotherm

$$\tan \theta = \frac{b}{a} = \frac{1}{n}$$

The intercept on the y-axis gives the value of $\log k$.

Freundlich isotherm explains the behaviour of adsorption in an approximate manner. The factor $1/n$ can have values between 0 and 1 (probable range 0.1 to 0.5). Thus, equation (i) holds good over a limited range of pressure.

When $1/n = 0$, $x/m =$ constant which shows that adsorption is independent of pressure. When, $1/n = 1$, $x/m = kP$, i.e., $x/m \propto P$. The adsorption varies directly with pressure. See graph in Fig. 13.3(b).
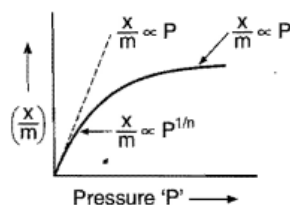

Fig. 13.3(b)

Both the above conditions are supported by experimental results. The experimental isotherms always seem to approach saturation at high pressure. This cannot be explained by Freundlich isotherm. Thus, it fails at high pressure.

Shortcomings of Freundlich adsorption isotherm:

(i) Concept of Freundlich adsorption is purely empirical.

(ii) It does not consider the role of surface area of adsorbent in the process of adsorption.

(iii) It is unable to explain, why the degree of adsorption is constant at higher pressure.

(iv) It is applicable for only physical adsorption because it considers multimolecular layer of adsorption.

The Freundlich adsorption isotherm was modified by Langmuir in 1916.

Langmuir adsorption isotherm: Langmuir (1916) derived a simple adsorption isotherm. He postulated the following theory of adsorption:

(i) Gases form unimolecular layer of adsorption on the surface of adsorbate.

(ii) Gases undergoing adsorption behave ideally.

(iii) Adjacent adsorbed molecules do not interact. In other words, adsorption of a gas molecule at a particular site is independent, whether the neighbouring sites are adsorbed or not.

(iv) Dynamic equilibrium exists on the surface of adsorbent, i.e., two opposite processes take place simultaneously on the surface of adsorbent.

(a) Adsorption or condensation of gas molecules on the surface of solid or adsorbent.

(b) Desorption or evaporation of gas molecules from the surface of adsorbent.

At the stage of adsorption equilibrium, the rate of adsorption becomes equal to the rate of desorption.

Let us derive mathematical relation of adsorption isotherm. Let θ is the fraction of surface area of adsorbent covered by the gas molecules, then $(1-\theta)$ will be the fraction of surface area base which is available for adsorption. Rate of adsorption depends on the fraction of surface area base and the pressure of gas on the surface of adsorbent.

$$\text{Rate of adsorption} = k_1 (1-\theta)P \qquad \ldots\text{(i)}$$

Rate of desorption is directly proportional to the fraction of surface area of adsorbent occupied.

$$\text{Rate of desorption} = k_2\theta \qquad \ldots\text{(ii)}$$

At equilibrium,

Rate of adsorption = Rate of desorption

$$k_1 (1-\theta)P = k_2\theta$$

$$\theta = \frac{k_1 P}{k_2 + k_1 P}$$

$$\theta = \frac{(k_1/k_2)P}{1+\left(\dfrac{k_1}{k_2}\right)P} = \frac{KP}{1+KP}$$

where,

$$K = \frac{k_1}{k_2} = \text{constant}$$

According to Langmuir, the degree of adsorption is directly proportional to the θ, i.e., fraction of surface area occupied.

$$\frac{x}{m} \propto \theta = \frac{k\,KP}{1+KP} = \frac{K'P}{1+KP} \qquad \ldots\text{(iii)}$$

where,

$$K' = kK$$

Equation (iii) can be rearranged as:

$$\frac{P}{(x/m)} = \frac{1}{K'} + \left(\frac{K}{K'}\right)P$$

It is of the form $y = c + mx$, *i.e.*, equation of straight line but not passing through origin. By plotting $\dfrac{P}{(x/m)}$ against 'P' we get a straight line.

Slope of the line $AB = \dfrac{K}{K'} = \tan\theta$

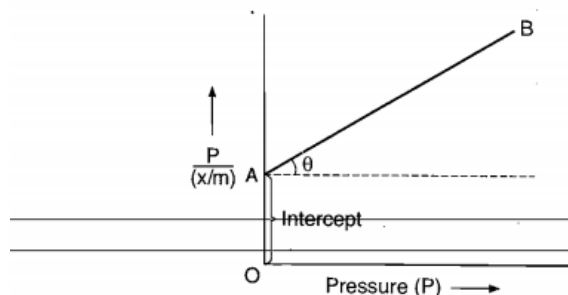Intercept of the line $= \dfrac{1}{K'} = $ length OA

Fig. 13.3(c) Plot of Langmuir adsorption isotherm

Interpretation of Langmuir adsorption isotherm: Let us consider the mathematical relation

$$\frac{x}{m} = \frac{K'P}{1 + KP}$$

Case I. When pressure is very high then $1 + KP \approx KP$

$\therefore$ $\dfrac{x}{m} = \dfrac{K'P}{KP} = $ constant

Thus, at high pressure, the degree of adsorption approaches a limiting value.

Case II. When pressure is low then $1 + KP \approx 1$

$\therefore$ $\dfrac{x}{m} = K'P$

Thus, degree of adsorption is directly proportional to pressure.

Case III. When pressure is moderate then expression is of the form $\dfrac{x}{m} = KP^{1/n}$; where, $\dfrac{1}{n}$ lies between 0 and 1.

Alternatively,

If Langmuir adsorption isotherm is expressed as:

$$\frac{x}{m} = \frac{aP}{1 + bP} \qquad \text{...(i)}$$

then, $$\frac{P}{(x/m)} = \frac{1}{a} + \frac{b}{a}P \qquad \text{...(ii)}$$

Thus, a plot of $\dfrac{P}{(x/m)}$ against will be a straight line with slope $\dfrac{b}{a}$ and intercept $\dfrac{1}{a}$.

Equation (i) may also be taken as:

$$\frac{m}{x} = \frac{b}{a} + \frac{1}{a} \times \frac{1}{P}$$

When, $\left(\dfrac{m}{x}\right)$ is plotted against $\dfrac{1}{P}$, we get straight line with slope $\left(\dfrac{1}{a}\right)$ and intercept $\left(\dfrac{b}{a}\right)$.

13.6 ADSORPTION FROM SOLUTION PHASE

Solids can adsorb solutes from solutions also. When a solution of acetic acid in water is shaken with charcoal, a part of the acid is adsorbed by the charcoal and the concentration of the acid decreases in the solution. The litmus solution when shaken with charcoal becomes colourless. The precipitate of $Mg(OH)_2$ attains blue colour when precipitated in presence of magneson. The colour is due to adsorption of magneson. The following observations have been made in the case of adsorption from solution phase:

(i) The extent of adsorption decreases with the increase of temperature.

(ii) The extent of adsorption increases with the increase of surface area of the adsorbent.

(iii) The extent of adsorption depends on the concentration of the solute in solution.

(iv) The extent of adsorption depends on the nature of the adsorbent and the adsorbate.

When the concentration of adsorbate is more on the surface of the adsorbent than in the bulk, it is called positive adsorption. If the concentration of the adsorbate is less relative to its concentration in the bulk, it is called negative adsorption.

The precise mechanism of adsorption from solution is not known. Freundlich's equation approximately describes the behaviour of adsorption from solution with the difference that instead of pressure, concentration of the solution is taken into account, *i.e.*,

$$\frac{x}{m} = kC^{1/n}$$

(C is the equilibrium concentration, *i.e.*, when adsorption is complete.)

On taking logarithm of the above equation, we have

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

Plotting $\log x/m$ against $\log C$ a straight line is obtained which shows the validity of Freundlich isotherm. This can be tested experimentally by taking solutions of different concentrations of acetic acid. Equal volumes of solutions are added to equal amounts of charcoal in different flasks. The final concentration is determined in each flask after adsorption. The difference in the initial concentration and final concentration gives the value of x. Using the above equation, validity of Freundlich isotherm can be established.

13.7 ADSORPTION ISOBARS AND ISOSTERE

A graph drawn between degree of adsorption (x/m) and temperature 't' at a constant pressure of adsorbate gas is known as adsorption isobar.
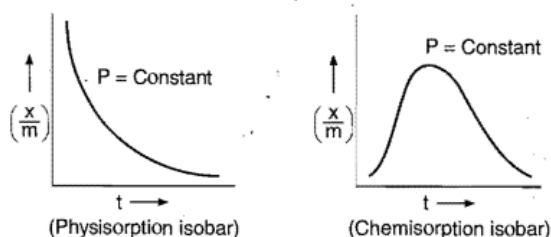
(Physisorption isobar)   (Chemisorption isobar)

Fig. 13.4

Adsorption isobars of physical and chemical adsorptions show an important difference and this difference is helpful in distinguishing these two types of adsorption.

Adsorption Isostere: Degree of adsorption depends on temperature as well as on pressure. When temperature increases, the extent of adsorption decreases. A linear relationship should exist between temperature and pressure with a certain amount of adsorption. *The plot of temperature versus pressure for a given amount of adsorption is called adsorption isostere.*
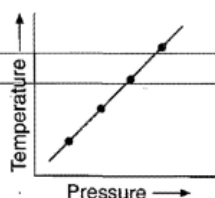

Fig. 13.5

Preferential Adsorption OR Competing Adsorption

Whenever a mixture is allowed to come in contact with a particular adsorbent under the same conditions, the more strongly adsorbable adsorbate is adsorbed to a greater extent irrespective of its amount present. A preferentially adsorbable adsorbate can displace a weakly adsorbed substance from the surface of the adsorbent.

Determination of Surface Area of Adsorbent

If V litre of a gas is adsorbed at temperature T and pressure 'P' then number of gas molecules adsorbed will be:

$$\text{Number of molecules} = \left(\frac{PV}{RT}\right) \times 6.023 \times 10^{23} \quad \ldots(i)$$

If monomolecular layer of adsorption is formed then:
Surface area of adsorbent
= Number of molecules × Area of cross-section of a molecule

Area of cross section of molecule is usually determined from the density of the liquefied or solidified adsorbate.

$$\text{Volume of gas molecule} = \frac{M}{\rho \times 6.023 \times 10^{23}}$$

$$\frac{4}{3}\pi r^3 = \frac{M}{\rho N_A}$$

$$r = \left[\frac{3}{4\pi}\frac{M}{\rho N_A}\right]^{1/3}$$

$$\text{Area of cross-section} = \pi r^2 = \pi\left[\frac{3}{4\pi}\frac{M}{\rho N_A}\right]^{2/3}$$

13.8 APPLICATIONS OF ADSORPTION

The phenomenon of adsorption finds a number of applications. Important ones are given here:

1. Production of high vacuum: A bulb of charcoal cooled in liquid air is connected to a vessel which has already been exhausted as far as possible by a vacuum pump. The remaining traces of air are adsorbed by the charcoal. This results in a very high vacuum.

2. Gas masks: Gas mask is a device which consists of activated charcoal or a mixture of adsorbents. This apparatus is used to adsorb poisonous gases and thus purify the air for breathing.

3. Humidity control: Silica and aluminium gels are used as adsorbents for removing moisture. These gels are used for controlling humidity of rooms. Silica gel is also used in desiccators.

4. Removal of colouring matter from solution: Animal charcoal removes colours of solutions by adsorbing coloured impurities. Animal charcoal is used as decolouriser in the manufacture of cane sugar.

5. Heterogeneous catalysis: Adsorption of reactants on the solid surface of the catalysts affects the rate of reaction between the reactants. The reaction proceeds more rapidly after adsorption. There are many gaseous reactions of industrial importance involving solid catalysts. Manufacture of ammonia using iron as a catalyst, manufacture of H_2SO_4 by contact process and use of finely divided nickel in the hydrogenation of oils are excellent examples of heterogeneous catalysis.

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

7. Softening of hard water: The hard water is made to pass through a column packed with zeolite (sodium aluminium silicate). Ca^{2+} and Mg^{2+} ions, which are responsible for hardness, get adsorbed on zeolite, exchanging sodium ions.

$$Na_2Al_2Si_2O_8 + CaCl_2 \longrightarrow CaAl_2Si_2O_8 + 2NaCl$$
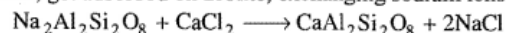
The exhausted zeolite is regenerated with 10% of sodium chloride solution.

$$CaAl_2Si_2O_8 + 2NaCl \longrightarrow Na_2Al_2Si_2O_8 + CaCl_2$$

8. Deionisation of water: Water can be deionised by removing all dissolved salts with the help of cation and anion-exchanger resin. Cation-exchanger is an organic synthetic resin such as polystyrene containing a macroanion ($R - SO_3^-$) which has adsorbed H^+ ions. A resin containing a basic group ($-N^+R_3$) which has adsorbed OH^- ions acts as anion-exchanger. The water containing dissolved salts is first passed through cation-exchanger and then through anion-exchanger. The cation-exchanger removes the cations by exchange with H^+ ions while anion-exchanger removes the anions by exchange with OH^- ions:
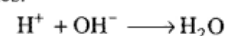
$$R^- - - - H^+ + Na^+ \longrightarrow R^- - - - Na^+ + H^+$$
Cation-exchanger
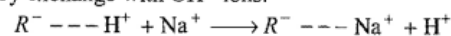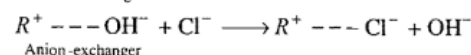
$$R^+ - - - OH^- + Cl^- \longrightarrow R^+ - - - Cl^- + OH^-$$
Anion-exchanger

The H^+ and OH^- ions thus produced react with each other to form water molecules.

$$H^+ + OH^- \longrightarrow H_2O$$

9. In curing diseases: A number of drugs are adsorbed on the germs and kill them or these are adsorbed on the tissues and heat them.

10. Cleaning agents: Soaps and detergents get adsorbed on the interface and thus reduce the surface tension between dirt and cloth, subsequently the dirt is removed from the cloth.

11. Froth floatation process: A low grade sulphide ore is concentrated by separating it from silica and other earthy matter by this method. The finely divided ore is added to water containing pine oil and foaming agent. The air is bubbled through the mixture. The foam formed rises to the surface on which mineral particles wetted with oil are adsorbed while earthy matter settles down at the bottom.

12. Adsorption indicators: Surfaces of certain precipitates such as silver halides have the property of adsorbing some dyes like eosin, fluorescein, etc. In the case of precipitation titrations (for example $AgNO_3$ *versus* NaCl) the indicator is adsorbed at the end point producing a characteristic colour on the precipitate.

13. Chromatographic analysis: The phenomenon of adsorption has given an excellent technique of analysis known as chromatographic analysis. The technique finds a number of applications in analytical and industrial fields.

14. Surfactants: Surfactants work as emulsifier in the manufacture of emulsion. The emulsifiers work on the principle of adsorption.

15. Adsorption and kinetics: Many reactions that occur on a metal surface are of zero-order, *e.g.,* decomposition of N_2O on platinum surface. It is because the rate determining step occurs on the surface itself. Once the surface of adsorbent gets covered by the reactant, the rate of reaction becomes independent of concentration of the reactant.