

## Adsorption, Colloidal state and Catalysis

### Adsorption.

Adsorption is the phenomenon of attracting & retaining the molecules of a substance on the surface of a liquid or a solid resulting into a higher concentration of the molecules on the surface. The substance adsorbed is called **adsorbate**. The substance on which it is adsorbed is called the **adsorbent**. Removal of the adsorbed substance from the surface is called **desorption**. The adsorption of gases on the surface of metal is called **occlusion**.

**Causes of adsorption** : Adsorption arises at the surface of solids as a result of the presence of unbalanced forces at the surface. These forces develop either during the crystallization of solids or by virtue of the presence of unpaired electrons in d-orbitals.

**Characteristics** : It is specific & selective in nature. It is accompanied by decrease in the free energy of the system. When  $\Delta G = 0$ , adsorption equilibrium is established. Adsorption is a spontaneous process therefore change in free energy ( $\Delta G$ ) for the process is negative. The free energy change is related to enthalpy change & entropy change by Gibb's Helmholtz equation,  $\Delta G = \Delta H - T\Delta S$ . Adsorption is an exothermic process. The entropy change of adsorption,  $\Delta S$  is -ve because adhering of gas molecules to the surface lower to randomness.

#### Type of adsorption :

Physisorption	Chemisorption
When a gas is held on the surface of a solid by weak Vander Waal's forces. The phenomenon is <i>physisorption</i> .	When a gas is held on the surface of a solid by forces similar to those of a chemical bond, the adsorption is known as <i>chemisorption</i> .
The forces operating in these cases are weak Vander Waal's forces.	The forces operating in these cases are similar to those of a chemical bond.
The heats of adsorption are low viz, about 20-40 kJ mol <sup>-1</sup> .	The heats of adsorption are high viz. about 40-400 kJ mol <sup>-1</sup> .
No compound formation takes place in these cases.	Surface compounds are formed.

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The process is reversible i.e. desorption of the gas occurs by increasing the temperature or decreasing the pressure.	The process is irreversible. Efforts to free the adsorbed gas give some definite compound.
It does not require any activation energy.	It requires activation energy.
This type of adsorption decreases with increase of temperature.	This type of adsorption first increases with increase of temperature. The effect is called activated adsorption.
It is not specific in nature i.e. all gases are adsorbed on all solids to some extent.	It is specific in nature and occurs only when there is some possibility of compound formation between the gas being adsorbed and the solid adsorbent.
The amount of the gas adsorbed is related to the ease of liquefaction of the gas.	There is no such correlation.
It forms multimolecular layer.	It forms unimolecular layer.

### Factors on which adsorption depends :

(1) Nature of adsorbent and adsorbate.

(2) *Surface area of adsorbent* : Greater the surface area greater is the adsorption.

(3) *Nature of the gas adsorbed* : The gas with higher critical temperature, has stronger Vander Waal's forces of attraction & hence is adsorbed to a greater extent.

(4) *Temperature* : Adsorption is exothermic so according to Le-chatelier's principle increase in temperature decreases adsorption & vice versa.

(5) *Pressure* : Increase in pressure at constant temperature decreases adsorption.

(6) Activation of the solid adsorbent i.e. increasing the adsorbing power of the solid adsorbent.

### Application of adsorption : Important applications of adsorption are :

(1) To produce high vacuum. (2) In gas masks to adsorb poisonous gases & to purify the gas for breathing. (3) In dehumidifiers silica and aluminium gels are used as adsorbent for removing moisture. (4) For decolourising. (5) For heterogeneous Catalysis. (6) For separation of inert gases. (7) In softening of hard water. (8) In curing disease – So many drugs are adsorbed on the germs and kill them. (9) Cleaning agents like soaps and detergents get adsorbed on the inter-surface and thus reduce the surface-tension between cloth and dirt. (10) In froth floatation process. (11) In adsorption indicators. (12) In chromatographic analysis – The

phenomenon of adsorption has given an excellent technique of analysis known as chromatographic analysis.

(13) In quantitative analysis.

### Adsorption Isotherm.

The plots of extent of adsorption ( $x/m$ ) versus pressure at constant temperature is called as *adsorption isotherms*.

**Freundlich adsorption isotherm** : It is an empirical equation expressing the relationship between the extent of adsorption ( $x/m$ ) and pressure ( $p$ ) at a particular temperature. The relationship is expressed by the equation,

$$\frac{x}{m} = k.P^{1/n}$$

Where  $x$  is the mass of gas adsorbed,  $m$  is the mass of adsorbent,  $P$  is the pressure of gas and  $k, n$  are constants. Another form of equations is,  $\log \frac{x}{m} = \log k + \frac{1}{n} \log P$

This is an equation of straight line. The slope of straight line gives the value of  $\frac{1}{n}$  and the intercept on the  $y$ -axis gives the value of  $\log k$ .

### Colloidal state.

A heterogeneous system of two immiscible phase is called *colloidal state*. These two phases are dispersion medium and dispersed phase. In these two first is continuous phase while second one is discontinuous phase.

On the basis of particle size substances are of three types :

(i) True solution ( $10^{-9} m$ ), (ii) Colloidal solution ( $10^{-9}$  to  $10^{-7} m$ ), (iii) Suspensions ( $10^{-7} m$ ).

### Classification of colloids.

Colloids can be classified as follows :

(1) State of appearance i.e. rigid appearance (called gels) or fluid like appearance (called sols).

(2) Affinity for dispersion medium.

(3) Size i.e. macromolecular or associated or multimolecular.

(1) **State of appearance :**

Dispersed phase	Dispersion medium	Name	Examples
Solid	Solid	Solid sol	Some coloured glasses, precious stones, alloys, minerals, pearls.
Solid	Liquid	Sol	Some paints, muddy water.
Solid	Gas	Aerosol	Smoke, dust, dust storm, volcanic dust
Liquid	Solid	Gel	Cheese, butter, jellies, curd, boot-polish
Liquid	Liquid	Emulsion	Milk, hair cream, emulsions
Liquid	Gas	Aerosol	Fog, mist, cloud
Gas	Solid	Solid foam	Pumice stone, foam rubber, bread, styrene foam.
Gas	Liquid	Foam	Froth, whipped cream.

(2) **Affinity for dispersion medium :**

Property	Lyophilic sols	Lyophobic sols
Ease of preparation	Prepared easily by directly mixing with the liquid dispersion medium.	Cannot be prepared directly. Prepared by special methods only.
Stability	They are quite stable and are not easily precipitated or coagulated.	They are easily precipitated by addition of a small amount of a suitable electrolyte.
Hydration	They are highly hydrated.	They are not much hydrated.
Reversible and irreversible nature	They are reversible in nature i.e. once precipitated can reform the colloidal sol by simply remixing with the dispersion medium.	They are irreversible in nature i.e. once precipitated cannot form the colloidal sol by simple addition of the dispersion medium.
Nature of substances	These sols are usually formed by the organic substances like starch, gum, proteins etc.	These sols are usually formed by the inorganic materials like metals, their sulphides etc.
Viscosity	Their viscosity is much higher than that of	Their viscosity is almost the same as that of the

	the medium.	medium.
Surface tension	Their surface tension is usually lower than that of the dispersion medium.	Their surface tension is nearly same as that of the dispersion medium.
Visibility	Their particles are neither visible nor detected easily by the ultra-microscope (by the scattering of light).	Their particles, though not visible, can be easily detected by an ultra-microscope.
Migration in an electric field	Their particles may migrate in either direction or may not migrate at all.	Their particles migrate in only one particular direction in the electric field.

### (3) On the basis of Size :

Multimolecular colloids	Macromolecular colloids	Associated colloids
They are formed by the aggregation of a large number of atoms or molecules which generally have diameters less than 1 nm, e.g. sols of gold, sulphur, etc.	They are molecules of large size eg. Polymers like rubber, nylon, starch, etc.	They are formed by aggregation of a large no. of ions in concentrated solution eg. Soap sol.
Their molecular masses are not very high.	They have high molecular masses.	Their molecular masses are generally high.
Their atoms or molecules are held together by weak vander Waal's forces.	Due to long chain, the vander Waal's forces holding them are comparatively stronger.	Higher is the concentration, greater are the vander Waal's forces.
They usually have lyophilic character.	They usually have lyophobic character.	Their molecules contain both lyophilic and lyophobic groups.

### Preparation of colloidal solutions.

(1) **Preparation of Lyophilic sols** : The colloidal solutions of lyophilic colloids like starch, gelatin etc. can be readily prepared by dissolving these substances in water.

(2) **Preparation of Lyophobic sols** : Lyophobic sols can be prepared by :

- (i) Dispersion methods,                      (ii) Condensation methods.

(i) **Dispersion methods:**

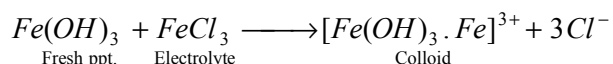
(a) *Mechanical disintegration* : It is carried with the help of colloidal mill. The substance is grinded virtually to the size of colloidal particles.

(b) *Ultrasonic dispersion* : In this method the ultrasonic vibrations having frequency larger than audible range can change the coarse suspension or liquids like oil, mercury, etc. to colloidal range.

(c) *Bredig's arc method* : This method is employed to prepare colloidal solutions of metals. The method involves passing electric current through electrodes made of metals whose solutions are to be prepared. A direct current is passed when an electric arc is formed and the metal passed into solution in colloidal form. Purple of cassius a colloidal solution of gold is obtained by this method.

(d) *Peptisation* : This method involves changing freshly prepared precipitates into colloidal form. Peptisation can be achieved as follows:

- *By adding excess electrolyte* to freshly prepared precipitates.



- *By adding another colloid.* For example, Lamp black is peptised by adding gums.
- *By washing precipitate.* For example, *CuS* and *BaSO<sub>4</sub>* washing continuously pass into colloidal form.
- *By adding organic solvents.* For example, a colloidal solution of cellulose nitrate is prepared in ethyl alcohol and ether. The product so obtained is commercially known as colloidion.

(ii) **Condensation methods** : Exchange of solvent and excessive cooling are other physical methods that can be employed to prepare colloidal solutions.

(a) **By change of physical state** : colloidal solutions of certain elements such as mercury and sulphur are obtained by passing their vapour through cold water containing a stabilizer.

(b) **By chemical methods** :

- *By double decomposition* :  $As_2O_3 + 3H_2S \rightarrow As_2S_3 + 3H_2O$   
(Colloidal sol.)
- *By reduction* :  $2AuCl_3 + 3SnCl_3 \rightarrow 2Au + 3SnCl_4$   
(Gold sol) (Classius purple)

- *By oxidation*:  $Br_2 + H_2S \rightarrow 2HBr + \underset{\text{(Colloidal sol)}}{S}$
- *By hydrolysis*:  $FeCl_3 + 3H_2O \rightarrow \underset{\text{(Ferric hydroxide sol)}}{Fe(OH)_3} + 3HCl$

### Purification of colloidal solution.

The process of reducing the impurities (electrolytes or soluble substances) to a requisite minimum in a colloidal solution is known as purification of colloidal solution.

**Dialysis** : The separation of soluble impurities from a colloidal solution on the basis of their different rates of diffusion through a parchment paper (semipermeable membrane) is known as dialysis. The small molecular or ionic species pass (diffuse) through the membrane pores while the colloidal particles which are larger in size do not pass through the membrane pores. In case of ionic nature of impurities, dialysis can be accelerated by taking advantage of electricity and the process is known as **electrodialysis**.

### Properties of colloidal solution.

Some characteristic properties shown by colloids are :

- (1) Sols are heterogeneous consist of two phases.
- (2) Colloidal particles have slow rate of diffusion through semipermeable membrane e.g., parchment paper.
- (3) Colloidal particles pass through ordinary filter papers
- (4) Colloidal particles do not settle down under the influence of gravity.
- (5) The colloidal particles cannot be seen even with a most powerful microscope as clear image formation of a particle smaller in size than the wavelength of light used is not possible. However, zones of scattered light can be seen by a microscope and sometimes with naked eye also.
- (6) *Colligative properties* : Like true solutions, colloidal solutions also exhibit colligative properties. These properties are of small order as compared to true solutions at same concentrations.
- (7) *Tyndall effect (Optical property)* : The colloidal particles absorb light, become self luminous and then scatter light in all possible directions. Some examples of tyndall effect are :
  - (i) Blue colour of sky and sea water.

(ii) Visibility of tails of comets and twinkling of stars.

(iii) Visibility of projector path and circus light.

(iv) Visibility of sharp ray of sunlight passing through a slit in dark room.

(8) *Electrophoresis (Electrical property)* : The migration of colloidal particles towards the oppositely charged electrodes under the influence of applied electric field is called electrophoresis. The electrical properties of colloids can also be explained by **electrical double layer theory**.

(9) *Brownian Movement (Mechanical or kinetic property)* : When a colloidal solution is examined under an ultramicroscope, the colloidal particles are seen to be in a state of continuous, rapid, random motion. This phenomenon is known as Brownian movement as it was first noticed by **Robert Brown**.

(10) *Coagulation* : Coagulation or Flocculation is the precipitation of a colloid through induced aggregation of its particles. Coagulation of a colloid can be achieved through following methods :

- (a) By addition of electrolyte, (b) By adding oppositely charged, (c) By destroying the stabilizing agent,
- (d) By heating, (e) By electrophoresis, (f) By repeated dialysis.

In addition, the colloids can be coagulated by many other ways :

- (a) Increase in temperature, (b) Addition of dehydration agents, (c) Agitation, (d) Centrifugal fields.
- (e) Presence of impurities.

**Coagulation value** : The minimum concentration of the electrolyte in millimoles per litre of the solution, required to cause coagulation of a particular sol is called coagulation value or flocculation value of the electrolyte for the sol. Therefore, Flocculation value  $\propto \frac{1}{\text{Coagulating power}}$

An electrolyte having greater coagulation value has smaller coagulating power.

**Hardy schulze rule** : Different electrolytes are known to have different coagulation values. The coagulating behaviour is governed by Hardly Schulze rule according to which :

(i) The ion having opposite charge to sol particles cause coagulation and

(ii) Coagulating power of an electrolyte depends on the valency of ion *i.e.*, greater the valency more is the coagulating power.



The decreasing order of flocculation value of electrolytes for a -ve sol is,  $NaCl > BaCl_2 > AlCl_3 > SnCl_4$

The decreasing order of flocculation value of electrolytes for a +ve sol is,  $KCl > Na_2SO_4 > Na_3PO_4 > K_4[Fe(CN)_6]$

### Gold number.

Lyophilic colloids protect the lyophobic colloids against their coagulation by addition of electrolytes. The protecting power of a lyophilic colloid is expressed in terms of gold number.

**Gold Number** : The number of milligrams of the protective colloid which just prevent the coagulation of 10 ml of standard red gold sol when 1 ml of 10% solution of sodium chloride is added to it. Smaller the gold number of the protective colloid greater is its protecting power. The gold number of a few lyophilic colloids are given below:

Gum Arabic	0.15 – 0.25	Potato starch	25
Gelatin	0.005 – 0.01	Caseinate	0.01
Egg albumin	0.15 – 0.25	Haemoglobin	0.03

**Congo rubin number** : Ostwald introduced Congo rubin number to account for protective nature of colloids. It is defined as the amount of protective colloid in milligrams which prevents colour change in 100 ml of 0.01% Congo rubin dye to which 0.16 g equivalent of  $KCl$  is added.

### Emulsions.

Emulsion is a colloidal solution of two immiscible liquids in which one liquid acts as the dispersed phase while the other liquid acts as the dispersion medium. There are two types of emulsions i.e.,

(1) Oil in water – Examples : milk, cream, face cream, etc.

(2) Water in oil – Examples : butter, cold cream etc.,

**Properties of emulsions :**

Property	Water in oil	Oil in water
Dispersed phase	Water	Oil

Dispersion medium	Oil	Water
Examples	Butter, cold cream, cod liver oil	Milk, face creams, butter creams
Viscosity	More than water	Slightly more than water
Appearance	Oily, opaque and translucent	Watery, opaque and translucent.
Electrical conductivity	Very low	Nearly equal to water.
Dilution test	More oil added is soluble but not water	More water added is soluble but not oil
Spreading test	Spreads easily on an oily layer.	Spreads readily on watery layer
Dye test : Addition of oil soluble dye like methylene blue	Dye dissolves giving a bright colour	Dye remains insoluble in the form of coloured droplets.

**Detection of type of emulsion :** These can be detected by :

(1) Dilution test, (2) Dye test, (3) Electrical conductivity, (4) Spreading test, (5) Viscosity test.

#### **Role of emulsions**

(1) Cleansing action of soaps and detergents.

(2) Milk, cream, butter are all emulsions and are important constituents of our food.

(3) Various cosmetics as cold cream, body lotions are emulsions.

(4) Digestion of fats in intestine is through emulsification.

(5) Various oily drugs are administered as emulsions for fast assimilation.

**Emulsifying agent :** It is added to an oil and water emulsion to increase its stability. It has a polar and non-polar groups, the former attaches to water and the latter to oil and so binds them together in an emulsion. Soaps and detergents act as emulsifying agents.

#### **Gels.**

Gels are colloidal systems in which liquids are dispersed phase and solids act as dispersion medium. Gels may shrink by losing some liquid held by them. This is known as **Synereises or Weeping**. Some gels are known to liquify on shaking and reset on being allowed to stand. This reversible sol-gel transformation is called **thixotropy**. Gels are two types :

(1) **Non elastic** : These are irreversible *i.e.*, when dehydrated these change into powder which cannot be changed back by addition of water.

(2) **Elastic** : These are reversible *i.e.* these can be changed back into original form even after dehydration.

### Applications of colloids.

The applications can be divided mainly into two classes :

(1) **Natural applications** : (i) Blue colour of sky, (ii) Fog, mist and rain, (iii) Food articles, (iv) Blood, (v) soils, (vi) Formation of delta.

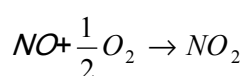
(2) **Technical applications** : (i) Electrical precipitation of smoke, (ii) Purification of drinking water, (iii) Medicines, (iv) Tanning, (v) Cleaning action of soaps and detergents, (vi) Photographic plates and films, (vii) Rubber industry, (viii) Paints, inks, plastics, lubricants, cement, etc.

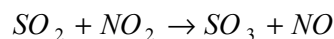
### Catalysis.

It is defined as a substance a small amount of which alters (increases or decreases) the velocity of a chemical reaction by its mere presence, without itself undergoing any change in mass and composition at the end of the reaction. This phenomenon of altering the velocity of a chemical reaction by the presence of catalyst is called **catalysis**. Catalytic reactions are broadly divided into two groups :

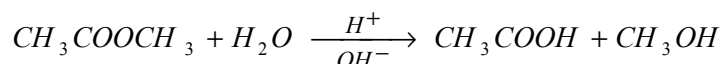
(1) **Homogeneous Catalysis** : Those catalytic reactions in which the catalyst as well as the reacting substances are present in the same physical state (phase) *i.e.* if the reactants are solids, the catalyst is solid. If the reactants are liquids or gases, the catalyst is also liquid or gas respectively. A few examples are as follows :

(i) **Gas phase catalysis** :  $SO_2$  is oxidised to  $SO_3$  in the presence of nitric oxide as a catalyst.

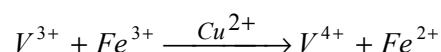




(ii) **Catalytic reaction in solution** : Hydrolysis of esters – Methyl acetate is hydrolysed more rapidly in the presence of  $H^+$  ions or  $OH^-$  ions.



(iii) **Electron transfer reaction** :  $Cu^{2+}$  catalyses the following reaction



(2) **Heterogeneous Catalysis** : Those catalytic reactions in which the physical state of reactants are different than the catalyst. A heterogeneous catalyst is a solid and the reactants are usually gases. The gases get concentrated on the surface of a solid catalyst through chemisorption and then the reaction proceeds to form the products. since the reaction takes place on the surface of the solid catalyst, heterogeneous catalysis is also called surface catalysis. eg.

- (i) Oxidation of  $CO$  in automobile exhaust by platinum catalysts.
- (ii) Zeigler method – Polymerisation of ethylene on titanium (IV) chloride ( $TiCl_4$ ) and trialkyl aluminium.
- (iii) Cracking of hydrocarbons in presence of hydrogen by zeolite catalysts.

#### Type of Catalysis :

(1) **Positive Catalysis** : When the rate of reaction is accelerated by a catalyst, it is said to be positive catalysis. Examples :

(i) Decomposition of  $H_2O_2$  in presence of colloidal platinum,  $2H_2O_2 \xrightarrow{Pt} 2H_2O + O_2$ .

(ii) Decomposition of  $MnO_3$  in presence of  $MnO_4$ .

(iii) Oxidation of ammonia in presence of platinum gauze.

(iv) Oxidation of  $SO_2$  in presence of NO.

(v) Oxidation of  $SO_2$  in presence of platinized asbestos or  $V_2O_5$ .

(vi) Oxidation of  $HCl$  into  $Cl_2$  by **Deacon's process** in presence of  $CuCl_2$ .

(vii) Hydrogenation of vegetable oil in presence of  $Ni$ .

(viii) Synthesis of  $NH_3$  by **Haber process** in presence of a mixture of iron &  $Mo$ .

(ix) Manufacture of methyl alcohol in presence of  $ZnO / Cr_2O_3$ .

(x) Formation of methane in presence of  $Ni$ .

(2) **Negative Catalyst** : There are certain catalysts which retard the reaction rate. these are called inhibitors and phenomenon is negative catalysis. Examples :

(i) The oxidation of sodium sulphite is retarded by alcohol.

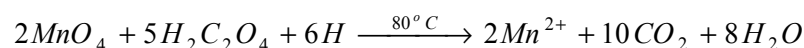
(ii) The decomposition of  $H_2O_2$  decreases in presence of glycerine.

(iii) The oxidation of chloroform by air is retarded by adding alcohol.

(iv) The oxidation of benzaldehyde is retarded by diphenyl amine.

(v) Tetra ethyl lead (TEL) acts as an antiknocking agent in the case of petrol.

(3) **Autocatalysis** : Some reactions are slow to start with but after some time they become quite rapid and this is due to the formation of one of the products (during the reactions), which acts as a catalyst. This phenomenon is called autocatalysis e.g., titration of potassium per manganate against oxalic acid acidified with  $H_2SO_4$ .



The disappearance of pink colour at the start of the titration is slow but later on it becomes rapid. This is due to the formation of  $Mn^{2+}$  ions which act as catalyst once they are formed. This is confirmed by the fact that if a crystal of  $MnSO_4$  is added in the beginning, the reaction is rapid from the start.

Thus hydrolysis of an ester by water is an autocatalytic process, since the acid liberated as a result of hydrolysis catalyses the reaction.  $RCOOR' + H_2O \rightleftharpoons RCOOH + R'OH$   
(Selfcatalyst)

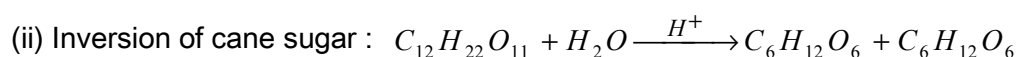
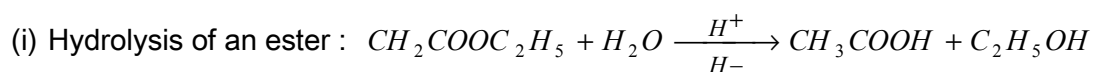
**Promoters** : The addition of a small amount of foreign substance which are not themselves catalytically active but sometimes increases the activity of the catalyst. These substances are termed as promoters. Examples:

(i) In the manufacture of ammonia by **Haber's process** in which finely divided  $Fe$  acts as a catalyst while molybdenum (or a mixture of  $Al_2O_3 + K_2O$ ) acts as a promoter.

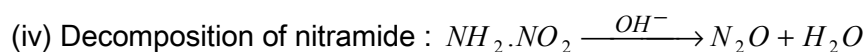
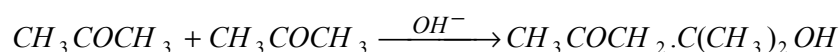
(ii) In the manufacture of  $CH_3OH$  from  $CO$  and  $H_2$  the activity of the catalyst  $ZnO$  is greatly enhanced by the presence of  $Cr_2O_3$ .

(4) **Acid – base catalysis** : Generally, homogeneous catalysis in solution is brought about by acids and bases. On the basis of studies done by **Arrhenius and Ostwald** in the hydrolysis of esters and nitrites, it was established that in acid –base catalysis, it is the hydrogen ion or hydroxyl ion which acts as catalyst .

Examples :



(iii) Conversion of acetone into diacetone alcohol :



(5) **Enzyme catalysis** : Enzymes are complex nitrogenous organic compounds which are produced by living plants and animals . Enzymes are actually high molecular mass protein molecules. Enzymes form colloidal solutions in water and are very effective catalysts. They catalyse numerous reactions, especially those connected with natural processes. Many enzymes have been obtained in pure crystalline state from living cells. However, the first enzyme was synthesized in the laboratory in 1969. The following are some of the examples of enzyme catalysis :

Enzyme	Source	Enzymatic reaction
Invertase	Yeast	Sucrose → Glucose and fructose
Zymase	Yeast	Glucose → Ethyl alcohol and carbon dioxide
Diastase	Malt	Starch → Maltose
Maltase	Yeast	Maltose → Glucose
Urease	Soyabeans	Urea → Ammonia and carbon dioxide
Pepsin	Stomach	Proteins → Amino acids
Trypsin	Intestine	proteins → Amino acids
Amylase	Saliva	Starch → Glucose
Lactic bacilli	Curd	Fermentation of milk
Mycoderma aceti	Vinegar	Ethyl alcohol → Acetic acid
Lipase	Castor seed	Fat → Glycerol
Ptylin	Saliva	Starch → Sugar

### Some industrial catalytic processes

Process	Catalyst
Haber's Process for the manufacture of ammonia. $N_2 + 3H_2 \rightleftharpoons 2NH_3$	Finely divided iron, Molybdenum as promoter. Conditions : 200 atmospheric pressure and 450–500 °C temperature
Ostwald's process for the manufacture of nitric acid. $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$ ; $2NO + O_2 \rightarrow 2NO_2$ $4NO + 2H_2O + O_2 \rightarrow 4HNO_3$	Platinised asbestos Temperature 300 °C
Lead chamber process for the manufacture of sulphuric acid $2SO_2 + O_2 \rightleftharpoons 2SO_3$ ; $SO_3 + H_2O \rightarrow H_2SO_4$	Nitric oxide.

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<p>Contact process for the manufacture of sulphuric acid.</p> $2SO_2 + O_2 \rightleftharpoons 2SO_3 ; SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ <p style="text-align: center;">Oleum</p>	<p>Platinised asbestos or vanadium pentoxide (<math>V_2O_5</math>).</p> <p>Temperature <math>400 - 450^\circ C</math></p>
<p>Deacon's process for the manufacture of hydrogen.</p> $4HCl + O_2 \rightarrow CO_2 + 2H_2$	<p>Cupric chloride (<math>CuCl_2</math>). Temperature <math>500^\circ C</math>.</p>
<p>Bosch's process for the manufacture of hydrogen.</p> $\underbrace{CO + H_2}_{\text{Water gas}} + H_2O \rightarrow CO_2 + 2H_2$	<p>Ferric oxide (<math>Fe_2O_3</math>) + chromic oxide as a promoter. Temperature <math>400 - 600^\circ C</math></p>
<p>Synthesis of methanol.</p> $CO + 2H_2 \rightarrow CH_3OH$	<p>Zinc oxide (<math>ZnO</math>) + chromic oxide as a promoter.</p> <p>Pressure 200 atmospheres and temperature <math>250^\circ C</math></p>
<p>Hydrogenation of vegetable oils</p> $\text{Oil} + H_2 \rightarrow \text{vanaspati ghee}$	<p>Nickel (finely divided.)</p> <p>Temperature <math>150^\circ C - 200^\circ C</math>. High pressure</p>
<p>Manufacture of ethyl alcohol by fermentation of molasses (sugar solution).</p> $C_{12}H_{22}O_{11} + H_2O \xrightarrow{\text{Invertase}} C_6H_{12}O_6 + C_6H_{12}O_6$ $C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2C_2H_5OH + 2CO_2$	<p>Invertase enzyme and zymase (yeast) enzyme</p> <p>Temperature <math>25 - 30^\circ C</math>.</p> <p>Conversion occurs in 2 or 3 days.</p>
<p>Manufacture of ethyl alcohol from starch.</p> <p>(a) Starch <math>\xrightarrow{\text{Diastase}}</math> Maltose</p> <p>(b) Maltose <math>\xrightarrow{\text{Maltase}}</math> Glucose <math>\xrightarrow{\text{Zymase}}</math> Alcohol</p>	<p>Germinated barley (diastase enzyme)</p> <p>Temperature <math>50 - 60^\circ C</math></p> <p>Yeast (maltase and zymase enzymes).</p> <p>Temperature <math>25 - 30^\circ C</math>.</p>
<p>Manufacture of acetic acid from ethyl alcohol.</p> $C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$	<p><b>Mycoderma aceti.</b></p> <p>Temperature <math>25 - 30^\circ C</math>.</p>
<p>Bergius process for the synthesis of petrol from coal.</p> $\text{Coal} + H_2 \rightarrow \text{Mixture of hydrocarbons}$	<p>Ferric oxide (<math>Fe_2O_3</math>). Temperature <math>475^\circ C</math>.</p> <p>Pressure 200 atmosphere.</p>

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