

IITM MURTHAL
Diploma 1st Year
Applied Chemistry Notes
Electrochemistry

ELECTROCHEMISTRY AND ITS IMPORTANCE:

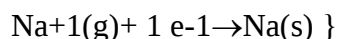
Electrochemistry is that branch of chemistry which primarily deals with the relation between chemical energy and electrical energy and their inter conversions. The principles of electrochemistry help us to understand production of electricity from energy released during chemical reactions and the use of electrical energy to carry out chemical reactions. Importance of Electrochemistry:

1. Extraction of more electropositive metals like Na, Mg, Ca, Al.
2. Electroplating, Electrolytic refining, Electrometallurgy.
3. Electrochemical cells and batteries and used in various instruments.
4. Understand corrosion of metals and develop preventive techniques.
5. Production of fuel cells.

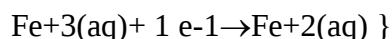
ELECTRONIC CONCEPT OF OXIDATION AND REDUCTION:

After establishment of atomic structure the electronic concept of oxidation and reduction is developed.

Oxidation: The oxidation is a process in which a substance loses one or more electrons. Consider the following examples:

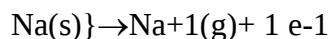


Sodium metal atom loses an electron, hence it is said to be oxidized to form sodium cation.

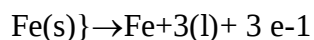


Ferrous ion undergoes oxidation by the loss of an electron to form ferric ion. Therefore, loss of electrons by a species is called oxidation. Here, species means it may be an atom or group of atoms or ion or a molecule.

Reduction: The reduction is a process in which a substance gains one or more electrons. Consider the following examples:



Sodium cation gains an electron, hence it is said to be reduced to form sodium metal atom. Thus, sodium metal is manufactured by the electrolytic reduction of molten sodium chloride.



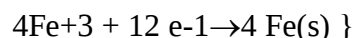
Ferric ion undergoes reduction by the gaining an electron to give iron. Thus, hematite ore is reduced to iron using coke in the blast furnace.

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Cupric ion gains two electrons hence undergo reduction to form copper. It is used in construction of Daniel cell. Therefore, gain of electrons by a species is called reduction.

Redox reaction: Oxidation and reduction take place simultaneously. Therefore, redox reaction is a process in which oxidation and reduction take place simultaneously. Let us consider the following reaction to understand oxidation, reduction, reducing agent and oxidizing agent.



1. Iron oxidized to form ferric ion. $6 \text{ Fe(s)} \rightarrow 6 \text{ Fe}^{3+}(\text{aq}) + 12 \text{ e}^{-}$
2. Oxygen undergoes reduction to give oxide ion. $3 \text{ O}_2(\text{g}) + 12 \text{ e}^{-} \rightarrow 6 \text{ O}^{2-}(\text{aq})$
3. Ferric ion combines with oxide ion to form ferric oxide.

(adding equation 1 and 2) It is now clear that iron undergoes oxidation due to loss electrons, and oxygen undergoes reduction due to gain of electrons, finally ferric oxide is formed. Therefore, ferric oxide formation reaction is a redox reaction as it involves oxidation of iron and reduction of oxygen simultaneously.

What is the action of iron on oxygen and vice versa? In above redox reaction iron can undergo oxidation only when oxygen undergoes reduction. Thus, iron force the oxygen to undergo reduction hence, iron is a reducing agent. On the other hand oxygen force the iron to undergo oxidation hence, it is oxidizing agent.

Summary Oxidation is loss of electrons by a species. A species which undergoes oxidation will act as reducing agent. Reduction is gain of electrons by a species. A species which undergoes reduction will act as oxidizing agent.

CONDUCTORS: Substances that allow electric current to pass through them are known as conductors. Examples of conductors are metals like copper, silver, iron, zinc and aqueous solution of NaCl, KCl, HCl etc.

Metallic Conductors or Electronic Conductors are Substances which allow the electric current to pass through them by the movement of electrons are called metallic conductors, e.g. Metals like copper, iron, aluminum, silver, gold etc.

Electrolytic Conductors or Electrolytes: Substances which allow the passage of electricity through their molten (fused) state or aqueous solution are called electrolytic conductors. In aqueous solution or molten state of electrolytes contain, ions. The migration of these ions help an electrolyte to conduct electricity, hence are called electrolytic conductors. e.g., aqueous

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solution of acids like HCl, H₂SO₄, HNO₃, CH₃COOH, bases like KOH, NaOH, NH₄OH and salts like NaCl, KCl, K₂SO₄ etc. The spontaneous splitting up of an electrolyte into ions in its molten or aqueous solution state is called ionization or dissociation. Examples for ionization are

$$\text{H}_2\text{O} \rightarrow \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq})$$
$$\text{HCl}(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq})$$

TYPES OF ELECTROLYTES: Electrolytes are of two types:

Strong electrolytes: The electrolytes which dissociate or ionize completely into ions in either molten or aqueous state are called strong electrolytes. e.g., HCl, H₂SO₄, HNO₃, KOH, NaOH, NaCl, KCl, K₂SO₄ etc.

Weak electrolytes: The electrolytes which dissociate into ions partially in their aqueous or molten state are called weak electrolytes, e.g., CH₃COOH, H₂CO₃, NH₄OH, AgCl etc.

ELECTROLYSIS: The process of decomposition of an electrolyte when electric current is passed through either its aqueous solution or molten state is called electrolysis.

NON- ELECTROLYTE: Substance which does not allow electricity to pass through either in its fused (molten) state or aqueous solution state is called non-electrolyte. Some examples of non-electrolytes are urea, sugar, glucose etc.

FARADAYS LAWS OF ELECTROLYSIS:

Faraday's first law of electrolysis: According to Faraday's first law of electrolysis, "The amount of the substance deposited or liberated at electrodes is directly proportional to the quantity of electricity passed through electrolyte." Mathematically, if 'W' is the mass of substance deposited or liberated at electrode

Then, $W \propto I \times t$ or $W = I \times t \times Z$ or $W = Q \times Z$, where $Q = It$

Here, I = current in ampere (A), t = time in second (s), Q = quantity of charge in coulomb (C). Z is a constant known as electrochemical equivalent of substance grams per coulomb (g/C). $Q = It$
When $I = 1 \text{ A}$, $t = 1 \text{ s}$ or $Q = 1 \text{ C}$, then, $W = Z$. Thus, electrochemical equivalent of the substance is the amount of the substance deposited or liberated on electrode, when 1A current is passed through its electrolytic solution for 1s. Quantity of electric charge (Q) = $(I \times t) \text{ C} = (1)$

Faraday's second law of electrolysis: According to Faraday's second law of electrolysis, "The amount of the substances deposited or liberated at the electrodes by passing the same quantity of electricity through solutions of different electrolytes is directly proportional to their equivalent weights or their electrochemical equivalents. Thus,

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$$\frac{\text{mass of } A}{\text{mass of } B} = \frac{\text{equivalent weight of } A}{\text{equivalent weight of } B}$$

$$\frac{w_1}{w_2} = \frac{E_1}{E_2}$$

$$\frac{QZ_1}{QZ_2} = \frac{E_1}{E_2}$$

Hence, electrochemical equivalent $\propto$ equivalent weight

ELECTROCHEMICAL CELL: A device which converts efficiently chemical energy of a redox reaction into electric energy.

Batteries: Two or more than two cells connected in series are known as battery. For a good quality battery it should be reasonably light, compact and its voltage should not vary appreciably during its use.

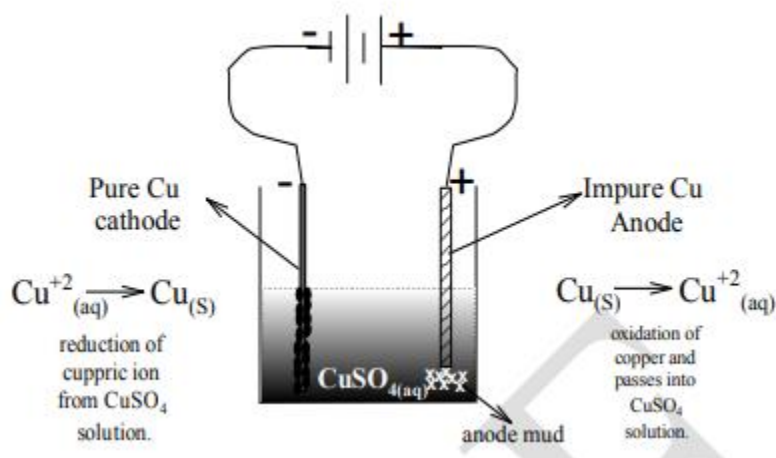
INDUSTRIAL APPLICATION OF ELECTROLYSIS: Some important application of electrolysis

Electrolytic refining: The process of purification of metals (crude or impure metal) by electrolysis method is called electrolytic refining. The metals like Copper and aluminum are refined (purified) by using electrolytic refining. The metal (say impure Cu) which is to be purified is connected with positive terminal of battery, which act as anode. The pure rod of same metal (say pure Cu) is connected with negative terminal of battery, which act as cathode. The solution of salt of same metal (say CuSO₄) acts as electrolyte. On passing current (electricity) the impure metal (anode) dissolve and pass into solution in the form of ions and same number of ions from solution deposit on cathode in the form of pure metal. More reactive metal impurities are passes into the solution. Other the impurities of less reactive metals settle below anode in the form of anode mud or anode sludge.

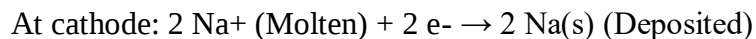
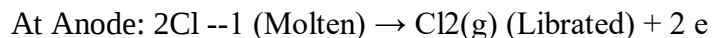
The process is shown by reaction below Anode: $\text{Cu (impure)} \rightarrow \text{Cu}^{2+} + 2 \text{e}^-$

Cathode: $\text{Cu}^{2+} + 2 \text{e}^- \rightarrow \text{Cu (pure)}$

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Electrometallurgy: The process of extraction of highly electropositive metals by electrolysis of their fused ore is called electrometallurgy. The more reactive metals like alkali metals (Li, Na, K), alkaline earth metals (Mg, Ca, Sr) and Aluminum (Al) are extracted from their ore by principles of electrometallurgy. Extraction of sodium from fused sodium chloride: Sodium is extracted from fused (molten) sodium chloride by electrolysis electrode reactions are as given below:

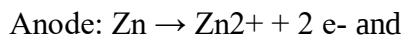


Electroplating: The process of coating a layer of superior metal on inferior metals surface by electrolysis is called electroplating. The electroplating is done

1 To protect the metal or alloy from corrosion.

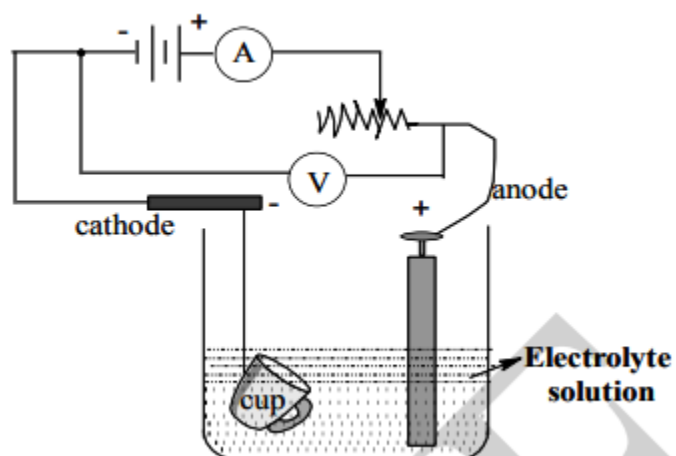
2 To improve the surface and provide aesthetic look to metal.

The metal (say Fe) which is to be electroplated or inferior metal is connected to negative terminal of battery, which act as cathode. The rod of superior metal (say Zn) is connected to positive terminal of battery, which act as anode. The solution of salt of pure metal (say ZnSO₄) acts as electrolyte. On passing current (electricity) the superior metal (anode) dissolve and pass into solution in the form of ions and same number of ions from solution deposit on cathode. The electrode reactions are given below



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Cathode: $\text{Zn}^{2+} + 2 \text{e}^- \rightarrow \text{Zn}$



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GENERAL PRINCIPLES OF EXTRACTION OF METALS

METALS AND NON-METALS:

Metals: The elements which are hard, dense, malleable, ductile, good conductor of electricity, electropositive in character and have bright luster and having high melting and boiling point are called metals. Examples are copper, silver, iron, aluminum etc.

Non-Metals: The elements which are generally not malleable, not ductile, bad conductor of electricity, electronegative in character are called non- metals. Examples are hydrogen, oxygen, carbon, sulfur etc.

MINERAL: The natural substance in which metal occur either in native state or in the combined state is called mineral.

Ore: The mineral from which the metal can be extracted easily and economical is called ore. e.g Hematite ($\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$) is ore of iron. Bauxite ($\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$) is the ore of aluminum Copper pyrite (CuFeS_2) is the ore of copper

DEFINITION OF METALLURGY: The extraction of metals from their chief ore is called metallurgy. 6.3.1 Types of metallurgy: Metallurgy is of three types:

a) Pyrometallurgy: Extraction of metals from their ore by heating with coke (carbon) or Carbon monoxide is called pyro-metallurgy. Iron (Fe) is extracted from Hematite ($\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$) by heating with coke.

b) Electrometallurgy: Extraction of metals from their ore by the process of electrolysis is called electrometallurgy. Aluminum is extracted from fused alumina mixed with cryolite by electrometallurgy.

c) Hydrometallurgy: The extraction of metal from their ore by dissolving unsuitable solvent then precipitating the metal from the solution by more reactive metal is called hydrometallurgy. Au (gold) and Silver (Ag) are extracted from their ore by hydrometallurgy.

GENERAL STEPS OF METALLURGY:

a) Crushing of ore: The process of converting big piece (lumps) of ore into smaller pieces is called Crushing of ore. It is done with the help of jaw crusher

b) Pulverization of ore: The process of converting crushed ore into powder form is called pulverization of ore. This process is carried with the help of ball mill or stamp mill.

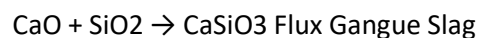
c) Concentration of ore/ benefaction process: The process of removing impurities from pulverized ore is called concentration of ore. Depending on the nature of ore and impurities the following methods are used for concentration of ore Gangue or matrix

The siliceous and earthy impurities of associated with ore is called gangue/ matrix.

Flux - The substance which is added in the ore to remove gangue (impurities) during reduction is called flux. It is of two types: Acidic flux: SiO_2 , Basic flux: CaO , FeO , MgO

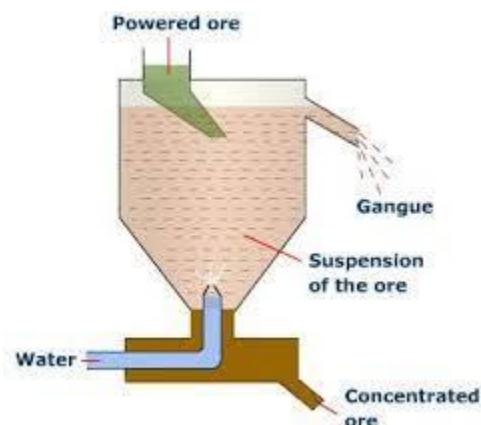
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Slag- The fusible mass formed by combination of flux and gangue is called slag.

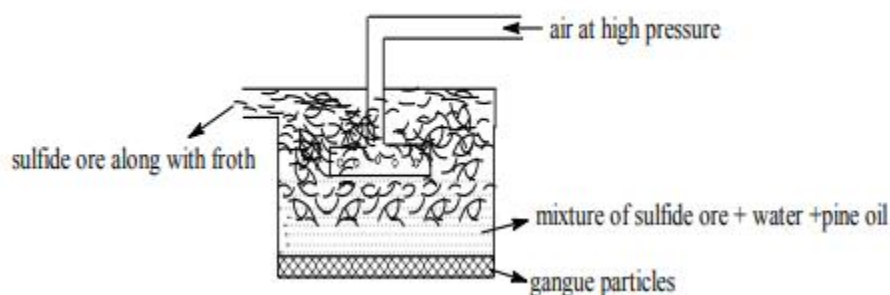


i) Gravity separation ii) Froth floatation process

Gravity separation method: This method is used for concentration of oxide and carbonate ore. It is based on the fact that ore particles are heavier than gangue. The pulverized ore is taken in a tank, stream of water enter in the tank at one end and leaves at other. The lighter gangue particles are carried by water whereas heavy ore particles settle at the bottom of the tank. Thus ore get concentrated. e. g., Hematite ($\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$) an ore of iron is concentrated by this method.



Froth floatation process: This process is generally used for concentration of sulfide ore like copper pyrite (CuFeS_2). Principle of froth floatation process: It is based on the principle that ore particles are preferentially wetted by oil while the impurities are preferentially wetted by water. In this method the pulverized ore is put in a tank containing mixture of water and pine oil. The air is drawn in the tank with perforated pipe. The oil form froth with air. The sulfide ore particles wetted by oil stick to froth; become lighter and rise to the surface whereas impurities wetted by water become heavy and settle down at the bottom of tank. The froth carrying the ore particles overflow into the settling tank where the ore settle down after sometime and get concentrated.

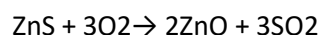


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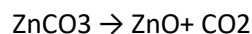
Oxidation of ore: The process of converting non oxide ore into oxide form is called oxidation of ore. Depending on the nature of ore the following methods are used for oxidation of ore.

i) Roasting ii) Calcination

Roasting: The process of heating concentrated ore in the excess of air below its melting point is called roasting. Roasting is carried out for the oxidation of sulfide ore like copper pyrite to oxide ore. The process of roasting and calcinations (oxidation of ore) carried out in reverberatory Furnace. During roasting the sulfide ore changes into oxide ore



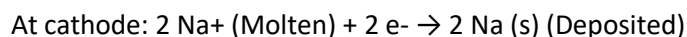
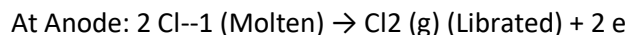
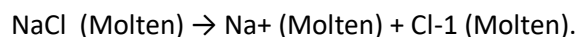
Calcination: The process of heating concentrated ore either in limited supply of air or in the absence of air below its melting point is called calcination. Calcination is the process of oxidation of oxide or carbonate ore like Hematite ($\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$), an ore of iron. The process of roasting and calcinations (oxidation of ore) is carried out in Reverberatory Furnace during calcination the Carbonate ore changes into oxide ore



Reduction: The process of obtaining metal from roasted or calcinated ore is called reduction. Depending on nature of metal and ore different methods of reductions are used. These are Smelting & Electrolytic reduction

Smelting: The process of extraction of metal from its ore by heating it with coke or CO at its melting point is called smelting. e.g. Iron is extracted from Hematite ($\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$) by heating with Coke

Electrolytic Reduction: The process of obtaining metal by passing electricity from molten state of its ore is called electrolytic reduction. The more reactive metal like aluminum, alkali metals (Li, Na, K) and alkaline earth metals (Mg, Ca) are obtained from their ore by electrolytic reduction. Or Extraction of metals from their ore by the process of electrolysis is called electrolytic reduction. The more reactive metal like aluminum, alkali metals (Li, Na, K) and alkaline earth metals (Mg, Ca) are obtained from their ore by electrolytic reduction. Extraction of sodium from sodium chloride: Sodium is extracted from fused (molten) sodium chloride by electrolysis electrode reactions are as given below:



Refining of metal:

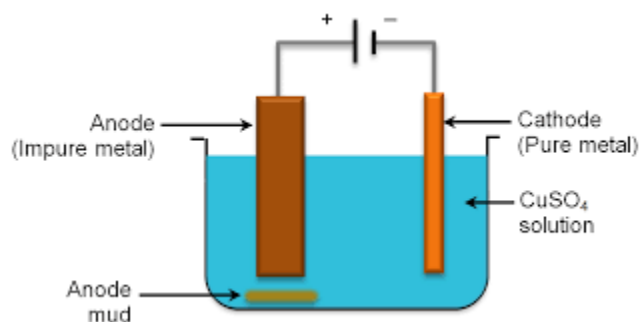
The process of removal of impurities from crude metal is called refining of metal. There are different methods of refining of metal depending on. Some of them are nature of metal and impurities. Some of them are

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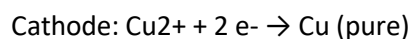
1. Electrolytic refining

2. Mond Process

Electrolytic refining: The process of purification of metals (crude or impure metal) by using electrolysis is called electro- refining. The metals like Copper and aluminum are refined (purified) by sing electrolytic refining.



The metal (say impure Cu) which is to be purified is connected with positive terminal of battery, which act as anode. The pure rod of same metal (say pure Cu) is connected with negative terminal of battery, which act as cathode. The solution of salt of same metal (say CuSO₄) acts as electrolyte. On passing current (electricity) the impure metal (anode) dissolve and pass into solution in the form of ions and same number of ions from solution deposit on cathode in the form of pure metal. More reactive metal impurities are passes into the solution. Other the impurities of less reactive metals settle below anode in the form of anode mud or anode sludge. The process is shown by reaction below



ALLOY: An alloy is homogeneous mixture of two or more metals or metals and non- metals. e.g., sodium amalgam is an alloy of sodium and mercury.

Types of alloys: Alloys are mainly of two types

1. Ferrous alloys: The alloys which contain iron as a main constituent is called ferrous alloys. Example Steel, invar, alnico are ferrous alloys.

2. Non-ferrous alloys: The alloys which not contain iron as a constituent is called non-ferrous alloys. Example Brass, bronze and solder, duralumin are non ferrous alloys.

Purpose of alloying: The main purpose of making an alloy is as follows:

1. To improve the hardness of metal: Alloys are made to make the metal hard e.g. pure iron is soft and cannot be used as such for machinery part. Thus it is mixed with small quantity of carbon to harden it.

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2. **To lower the melting point of metal:** The melting point of an alloy is lower than its constituents. The solder an alloy of lead and tin has lower melting point than both

3. **To increase the tensile strength:** The alloying is used to increase the tensile strength of metals. Addition of 1% carbon increases the tensile strength of pure iron by 10 times

4. **To prevent metal from corrosion:** Alloy is made to prevent metal from corrosion. For example (e.g.) iron can be protected from corrosion by alloying it with Cr for making steel

5. **To modify color:** Alloy is made to modify the color of metal. e.g. Brass, an alloy of copper and Zn has beautiful golden color.

FUELS

A substance that produces useful energy when undergoes combustion. This energy produced can be used economically for domestic and industrial purpose. Example – Coal, wood, diesel, CNG etc

Role of fuel in daily life

1. Fuels like LPG, wood, coal, etc are used in homes for cooking purpose
2. Petrol is used in the generation of electricity, used in transportation as fuel for automobiles and jets.
3. Coal is used in the generation of electricity. It is used in steel industry, pharmaceutical industry, cement manufacture, manufacturing of paper etc.
4. Natural gas is used in transportation as CNG or LNG.
5. Fuels like liquid hydrogen are used in space propellers like rockets

Characteristics of good fuel

- High calorific value
- Moderate ignition temperature
- Low moisture content
- Low non combustible matter
- Moderate velocity of combustion
- Products of combustion not harmful
- Low cost
- Easy to transport
- Combustion should be controllable
- No spontaneous combustion
- Low storage cost
- Should burn in air with efficiency.
- Should be easily available
- Minimum release of smoke and poisonous gas

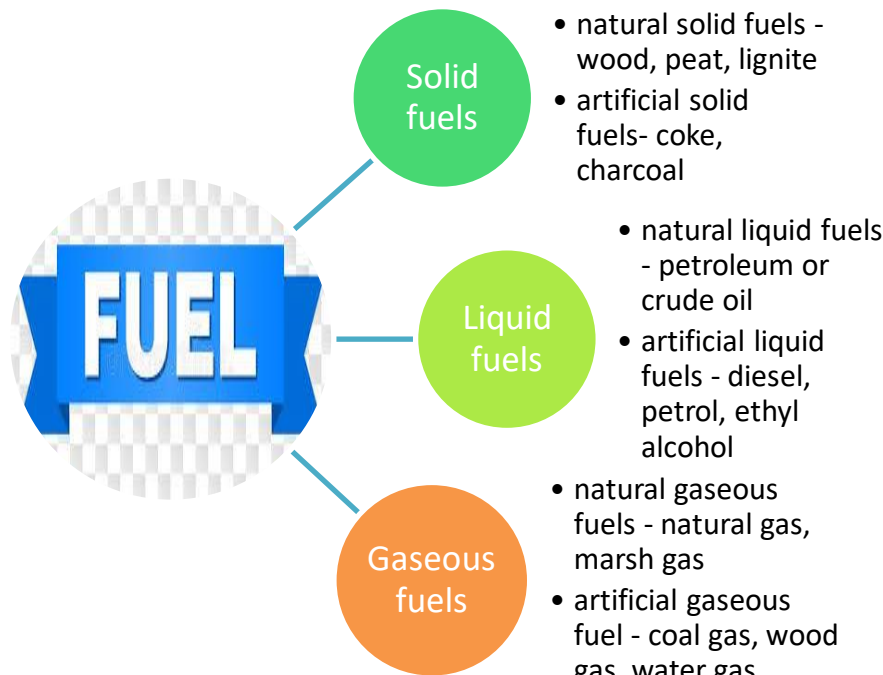
Classification of fuels

Fuels can be classified on 2 basis

1) On basis of their source -:

- A) Natural fuels – fuels which occur in nature
- B) Artificial fuels – which are prepared artificially

2) On basis of their physical state at room temperature



Calorific value of a fuel

Calorific value of fuel is the total quantity of heat liberated when a unit mass or volume of fuel is completely burnt. Its unit is cal/g

Proximate analysis of coal

The proximate analysis determines only the Fix carbon, Volatile matter, Moisture and Ash percentage in the coal sample given for analysis To carry out proximate analysis very simple apparatus are required.

Measurement of moisture:

- It is carried out by placing a weighted powder sample of coal in an uncovered crucible and it is placed in the oven at 108 centigrade for 1 hour
- The sample is cooled to room temperature and weighed again. The loss of weight represents moisture.
- This process of heating, cooling and weighing is repeated till the reading of weight becomes constant
- The % of moisture can be calculated as –
Weight of empty crucible = m_1 g
Weight of crucible + coal sample = m_2 g
Weight of crucible + anhydrous coal after heating = m_3 g

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Weight of coal sample taken = $(m_2 - m_1)$ g

weight of anhydrous coal = $(m_3 - m_1)$ g

Loss in weight = $(m_2 - m_1) - (m_3 - m_1) = (m_2 - m_3)$ g

$$\% \text{ of moisture} = \frac{\text{loss in weight of coal}}{\text{weight of coal taken}} \times 100$$

$$= \frac{(m_2 - m_3)}{(m_2 - m_1)} \times 100$$

Measurement of the volatile matter:

- Determination of volatile matter is carried out by taking a weighed fresh sample of coal and is placed in the covered crucible and is heated in the furnace at 900 plus minus 15-degree centigrade.
- The sample is cooled and weighed.
- The loss of weight represents Moisture+ Volatile matter
Weight of empty crucible = m_1 g
Weight of crucible + coal sample = m_2 g
Weight of crucible + anhydrous coal after heating = m_3 g
Weight of crucible and coal left after evaporation of volatile material = m_4 g
Weight of coal sample taken = $(m_2 - m_1)$ g
weight of volatile material = $(m_3 - m_4)$ g

$$\% \text{ of volatile material} = \% \text{ of moisture} = \frac{\text{weight of volatile material removed}}{\text{weight of coal taken}} \times 100$$

$$= \frac{(m_3 - m_4)}{(m_2 - m_1)} \times 100$$

Measurement of ash

- It is carried out by placing a weighted powder sample of coal in an uncovered crucible and it is placed in the oven at 800 centigrade for 1 hour
- The sample is cooled to room temperature and weighed again
- This process of heating, cooling and weighing is repeated till the reading of weight becomes constant
- Knowing the weight of ash its % can be calculated

Weight of empty crucible = m_1 g

Weight of crucible + coal sample = m_2 g

Weight of crucible + ash formed = m_5 g

Weight of coal sample taken = $(m_2 - m_1)$ g

Weight of ash formed = $(m_5 - m_1)$ g

$$\text{Weight of the ash formed} = \frac{\text{weight of volatile material removed}}{\text{weight of moisture free coal taken}} \times 100$$

$$= \frac{(m_5 - m_1)}{(m_2 - m_1)} \times 100$$

Measurement of fixed carbon

The percentage of carbon alone in the sample of coal is called the % of fixed carbon. To get the % of fixed carbon

% of fixed carbon = $100 - (\% \text{ of ash} + \% \text{ of moisture} + \% \text{ of volatile matter})$

Importance of proximate analysis

Proximate analysis provides following valuable information –

Fix carbon:

- Fix carbon acts as a main heat generator during burning.
- Fix carbon gives a rough estimate of heating value of coal

Volatile matter:

- Volatile matter also contributes to the heating value of coal
- Increase in percentage of volatile matter in coal proportionately increases flame length and helps in easier ignition of coal
- Sets of minimum limit of furnace height and volume
- Influences secondary oil support

Ash:

- Ash is an impurity which will not burn
- Ash content is important in design of furnace grate, combustion volume, pollution control equipment (ESP) and Ash handling plant
- Ash increases transportation, handling, storage cost
- Ash affects combustion efficiency and boiler efficiency
- Ash causes clinkering and slagging problems in boiler

Moisture:

- Moisture increases transportation, handling, storage cost
- Moisture decreases the heat content per kg of power plant coal
- Moisture increases heat loss due to evaporation and superheating of vapor
- Moisture helps in binding the fines
- Moisture helps in radiation heat transfer

Advantages of gaseous fuels over solid and liquid fuels

1. Gaseous fuels produce little or no smoke, whereas most of the solid fuels burn with smoke.
2. Gaseous fuels can be transported easily through pipelines.
3. Gaseous fuels have relatively low ignition temperature and hence they burn more easily than solid fuels.
4. Gaseous fuels do not leave any residue after burning.
5. They are easier to handle.
6. They are clean to use
7. They have high calorific value
8. They are more economical compared to solid and liquid fuels.

LPG (Liquefied petroleum gas)

Composition

Liquefied Petroleum Gas (LPG) is a blend of light hydrocarbon compounds. It mainly consists of -:

- i. n-butane
- ii. Isobutane
- iii. Butylene and propane

Uses of LPG

- **Heating and Cooking** - especially in locations that are not connected to local gas distribution systems.
- **Auto gas** - Consumption of auto gas is enhanced through low taxes. In 2008, more than 13 million cars ran on LPG globally. Industries are currently promoting the spread of car gas.
- Furthermore, LPG is used for cooling and in the Petrochemical industry.

Calorific value

LPG has a typical specific calorific value of 50KJ/g

CNG (Compressed natural gas)

Composition

CNG (Compressed Natural Gas) is composed primarily of methane, but may also contain ethane, propane and heavier hydrocarbons. Small quantities of nitrogen, oxygen, carbon dioxide, sulfur compounds, and water may also be found in natural gas.

Uses of CNG

CNG is used in traditional gasoline/internal combustion engine automobiles that have been modified or in vehicles specifically manufactured for **CNG** use.

Calorific value

CNG has calorific value of 30KJ/g

Bio Gas

Composition

Biogas is primarily composed of methane gas (50-60%), carbon dioxide (30-40%), nitrogen (2-6%), hydrogen (5-10%), carbon monoxide, hydrogen sulphide.

Uses of Bio Gas

The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel; it can be used for any heating purpose, such as cooking. It can also be used in a gas engine to convert the energy in the gas into electricity and heat.

Calorific value

12000kCal/m³

Octane Number

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An octane rating, or octane number, is a standard measure of the performance of an engine or aviation fuel. The higher the octane number, the more compression the fuel can withstand before detonating

OR

The octane number seen on pumps at gasoline stations is a value used to indicate the resistance of a motor fuel to knock—that is, to make pinging or ticking sounds in a car's engine when you step on the gas pedal. Octane number is also known as octane rating. Octane numbers are based on a scale on which isooctane is 100 (minimal knock) and heptane is 0 (bad knock). The higher the octane number, the more compression is required for fuel ignition. Fuels with high octane numbers are used in high performance gasoline engines. Fuels with low octane number are used in diesel engines, where fuel is not compressed.

Cetane Number

Cetane number (cetane rating) is an indicator of the combustion speed of diesel fuel and compression needed for ignition.

The CN is an important factor in determining the quality of diesel fuel.

In a particular diesel engine, higher cetane fuels will have shorter ignition delay periods than lower Cetane fuels. Generally, diesel engines operate well with a CN from 48 to 50. Fuels with lower cetane number have longer ignition delays, requiring more time for the fuel combustion process to be completed. Hence, higher speed diesel engines operate more effectively with higher cetane number fuels.

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Lubricant

A lubricant is a substance, introduced to reduce friction between surfaces in mutual contact, which ultimately reduces the heat generated when the surfaces move. This minimizes the wear and tear by the heat developed.

Lubrication

The action of applying a lubricant to an engine or between the sliding surfaces so as to minimize friction and allow smooth movement is called lubrication.

Functions of Lubricants

- The primary function of a lubricant is to prevent friction by creating a boundary layer between two surfaces
- Reduce the loss of energy in the form of heat and acts as coolant
- Transport contaminants to filters
- Protects from oxidization and corrosion
- It reduces the maintenance and running cost of maintenance

Classification of lubricants

On the basis of their physical state we can classify lubricants as -:

1. **Liquid lubricants** - The primary function of a liquid lubricant is to keep friction, wear and heat from affecting the sliding surfaces by providing a layer of liquid between the surfaces. They are classified as follows –:
 - a) Mineral oils – They are obtained by fractional distillation of petroleum. Examples are white oil, paraffin oil, liquid paraffin.
 - b) Vegetable oils - Vegetable oils, or vegetable fats, are oils extracted from seeds, or less often, from other parts of fruits. Examples are olive oil, palm oil, castor oil, hazel nut oil.
 - c) Animal oils – They are extracted from crude fat of animals. Examples are whale oil, lard oil, tallow oil.
 - d) Blended oils – When mineral oil is mixed with animal oil or vegetable oil to act as good lubricant, the mixture is called blended oil. Examples are typically, blended

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oils combine higher smoke point oil, such as vegetable, canola, peanut or corn, with lower smoke point oil, such as extra virgin olive, coconut or sesame oil.

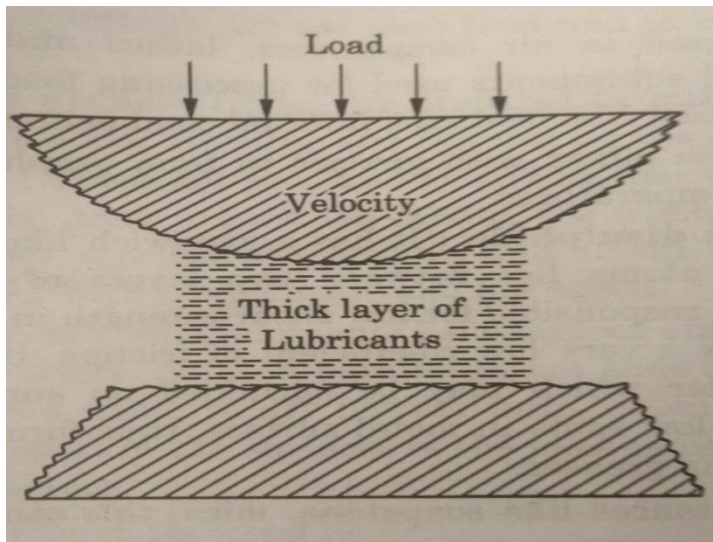
- e) Synthetic oils – These oils are chemically prepared compounds. Examples dialkylated benzenes, poly-isobutylene (PIB), poly(internal olefins) (PIOs), and phosphate esters.
- 2. **Semi-solid lubricants** - The most important semi-solid lubricants are grease, Vaseline, waxes and other compounds of oil and fats. These are called semi-solid because they are neither solids nor liquids at ordinary temperatures. Grease may be classified as :-
 - a) Calcium based grease
 - b) Soda based grease
 - c) Lithium soap grease
 - d) Axle grease
- 3. **Solid lubricant** - Dry lubricants or solid lubricants are materials that, despite being in the solid phase, are able to reduce friction between two surfaces sliding against each other without the need for liquid oil medium. The two main dry lubricants are graphite and molybdenum disulfide.

Types / mechanism of lubrication

Hydrodynamic lubrication

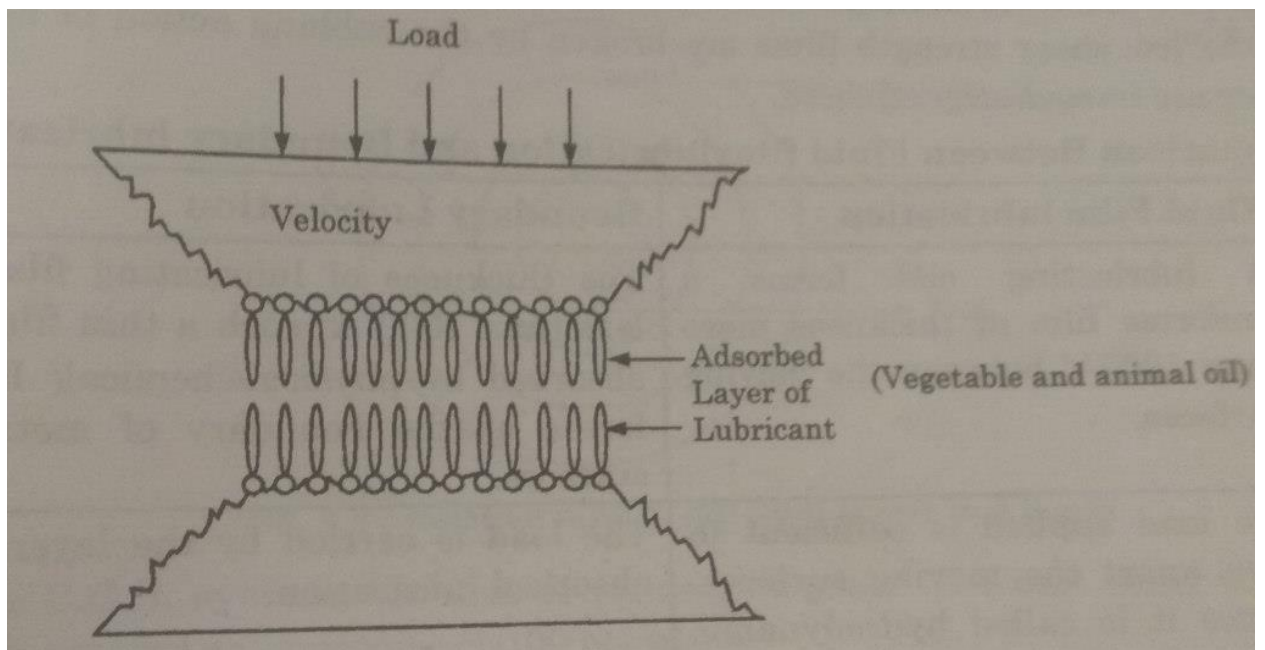
Hydrodynamic Lubrication is lubrication with the aid of liquid lubricant. The lubricant separates the rubbing surfaces by creating a film. So instead of shearing solids, the lubricant layers are sheared and this typically reduces friction. It is the most common type of lubrication and probably is the most explored. The lubricant film fills the irregularities of the sliding surfaces and forms a thick layer in between them, so that there is no direct contact between the materials surfaces this consequently reduces wear. The resistance to movement of parts is only due to the internal resistance between the particles of lubricant moving over each other. Therefore the lubricant chosen should have minimum viscosity and thickness.

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Boundary lubrication

Boundary lubrication is defined as that in which the sliding surfaces are separated by a very thin molecular film of lubricant, so that the chemical and physical natures of the surfaces and the lubricant are of major importance. This type of lubrication is one when, a continuous film of lubricant cannot persist and direct metal to metal contact is possible.



Physical Properties of Lubricants

Viscosity – Viscosity is the property of a liquid by virtue of which it offers resistance to its flow.

OR

Viscosity may be defined as the force in dynes required moving 1cm² of the liquid surface over another surface with a velocity of 1cm per second.

In CGS system the units of viscosity is 'Poise'

In SI system the unit of viscosity is Newton-second per square meter (Ns/M²)

1Ns/M² = 10 poise

- The reciprocal of the viscosity is called the fluidity, a measure of the ease of flow.
- Viscosity determines the performance of oil under the operating conditions. In case of machine moving at slow speed, a heavy oil (high viscosity) should be used as lubricant and for machine moving at fast speed, a light oil (low viscosity) should be used.

Coefficient of viscosity – The force of friction between two layers of fluid having the area in square centimeter and separated by distance will have a velocity is given by:

$$F = \eta \times \frac{v}{x}$$

Here,

η is coefficient of viscosity & $\frac{v}{x}$ is velocity gradient

The coefficient of viscosity is defined as the force of friction that is required to maintain a difference of velocity of 1cm/s between parallel layers of fluid. The unit is usually expressed in poise or centipoise.

Effect of temperature on viscosity – viscosity is due to intermolecular forces between the molecules of liquid. As the temperature raises the average kinetic energy of the molecules increases which in turn decreases the intermolecular forces. So we can conclude that with increase in temperature viscosity decreases.

Viscosity index - The viscosity index (VI) is an arbitrary, unit-less measure of a fluids change in viscosity relative to temperature change. It is mostly used to characterize the viscosity-temperature behavior of lubricating oils. The lower the VI, the more the viscosity is affected by changes in temperature

Oiliness – It is defined as the power of an oil to maintain a continuous film under pressure when used as lubricant.

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The term “oiliness” is defined as that property of lubricants by virtue of which one fluid gives lower coefficients of friction (generally at slow speeds or high loads) than another fluid of the same viscosity

Volatility - Volatility describes how easily a substance will vaporize (turn into a gas or vapor). If a lubricant is highly volatile, it will vaporize even at low temperature. In such case consumption of lubricant will be high and lubrication will be costly.

Flash and fire point – The fire point of a fuel is the lowest temperature at which the vapour of that fuel will continue to burn for at least 5 seconds after ignition by an open flame of standard dimension. At the flash point, a lower temperature, a substance will ignite briefly, but vapor might not be produced at a rate to sustain the fire.

Cloud and pour point - **Pour point** and **cloud point** are two important physical properties of any fuel or lubricant. • While **cloud point** refers to the temperature at which there is a presence of a wax cloud in the fuel

Pour point is the lowest temperature at which the fuel can flow and below which the fuel tends to freeze or ceases to flow

Chemical Properties of Lubricants

TAN (Total acidity number) - Total acid number. The **total acid number** (TAN) is a measurement of **acidity** that is determined by the amount of potassium hydroxide in milligrams that is needed to neutralize the acids in one gram of oil. It is an important quality measurement of crude oil. A good lubricant is which that has no free acid present.

Emulsification – Emulsification is the property of oils to get mixed with water forming a mixture called emulsion. The emulsion has the property of absorbing dust particles and foreign matter present in the surroundings. A good lubricant is that which does not forms any emulsion and if it is formed, it should not remain for a very long time.

Aniline point - The aniline point of oil is defined as the minimum temperature at which equal volumes of aniline and lubricant oil are miscible, i.e. form a single phase upon mixing.

Iodine value - The **iodine value** indicates the degree of unsaturation of a fat or oil. It is defined as the number of grams of iodine absorbed by 100 g of fat. Iodine value of a pure compound can be calculated as -:

$$\text{Iodine value} = 100 \times \frac{253.81 \times db}{mw_f}$$

db = no of double bonds

mw_f = molecular weight of fatty compound

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Polymers

A polymer is a large molecule made up of chains or rings of linked repeating subunits, which are called monomers. Polymers usually have high melting and boiling points. Because the molecules consist of many monomers, polymers tend to have high molecular masses.

Monomers

Monomer is a molecule that can react with other molecules to form very large molecules, or polymers. The essential feature of a monomer is polyfunctionality, the capacity to form chemical bonds to at least two other monomer molecules.

Polymerization

The process by which monomers are converted into polymers is called polymerization.

Degree of polymerization

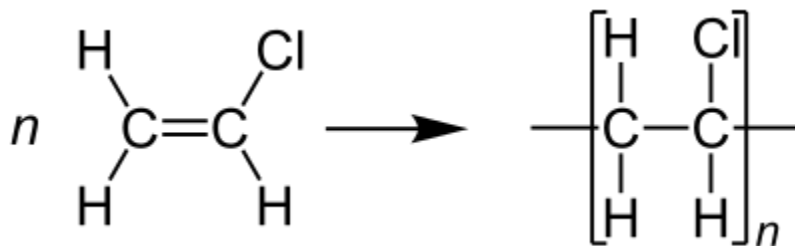
The degree of polymerization, or DP, is the number of repeating units in a polymer. The polymers which have low degree of polymerization are called oligomers and those with high degree of polymerization are called high polymers.

Addition and Condensation polymers

On the basis of synthesis polymers are of 2 types -:

Addition polymers - An addition polymer is a polymer that forms by simple linking of monomers without the co-generation of other products. Examples are - :

1. **Polyvinyl chloride (PVC)** – PVC is obtained by heating a water emulsion of vinyl chloride in presence of small amount of benzyl peroxide.



Properties

- a) Density: PVC is very dense compared to most plastics
- b) Economics: PVC is readily available and cheap.
- c) Hardness: Rigid PVC is very hard.

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- d) Strength: Rigid PVC has extremely good tensile strength.
- e) It is colorless, odorless, non-inflammable and chemically inert powder resistant to light

Uses - Economical, versatile polyvinyl chloride is used in a variety of applications in the building and construction, health care, electronics, automobile and other sectors, in products ranging from piping and siding, blood bags and tubing, to wire and cable insulation, windshield system components and more.

2. **Polythene** – Ethene undergoes polymerization to give polythene in the presence of oxygen and under high pressure



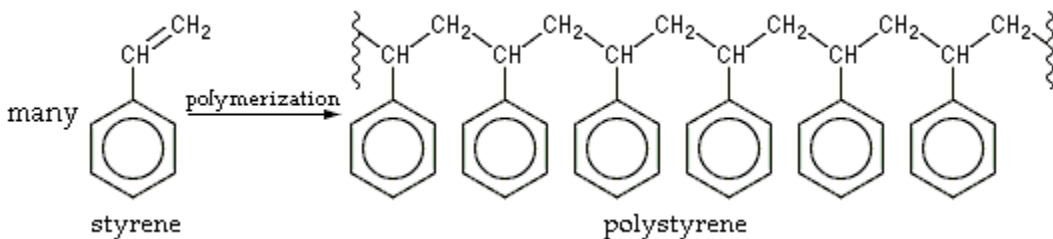
Properties -

- Excellent resistance to most solvents. Very good resistances to alcohols, dilute acids and alkalis. Moderate resistance to oils and greases. Poor resistance to hydrocarbons
- Polyethylene is of low strength, hardness and rigidity, but has a high ductility and impact strength as well as low friction.

Uses - Polyethylene is a member of the important family of polyolefin resins. It is the most widely used plastic in the world, being made into products ranging from clear food wrap and shopping bags to detergent bottles and automobile fuel tanks.

- 3. Polystyrene** - Polystyrene is a polymer that can be prepared by a monomer addition process. The addition reaction is catalyzed by radical cations or anions.

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Uses and properties

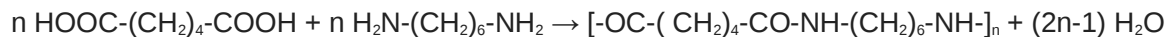
Polystyrene can be solid or foamed. General-purpose polystyrene is clear, hard, and rather brittle. It is an inexpensive resin per unit weight. It is a rather poor barrier to oxygen and water vapor and has a relatively low melting point. Polystyrene is one of the most widely used plastics, the scale of its production being several million ton per year. Polystyrene can be naturally transparent, but can be colored with colorants. Uses include protective packaging (such as packing peanuts and CD and DVD cases), containers, lids, bottles, trays, tumblers, disposable cutlery and in the making of models.

Condensation polymers

Condensation polymers are any kind of polymers formed through a condensation reaction—where molecules join together—losing small molecules as byproducts such as water or methanol.

Examples are -:

1. **Nylon – 66** - Nylon 66 is a type of polyamide or nylon. Nylon 6, is most common for textile and plastic industries. Nylon 66 is made of two monomers each containing 6 carbon atoms, hexamethylenediamine and adipic acid, which give nylon 66 its name.



Properties:

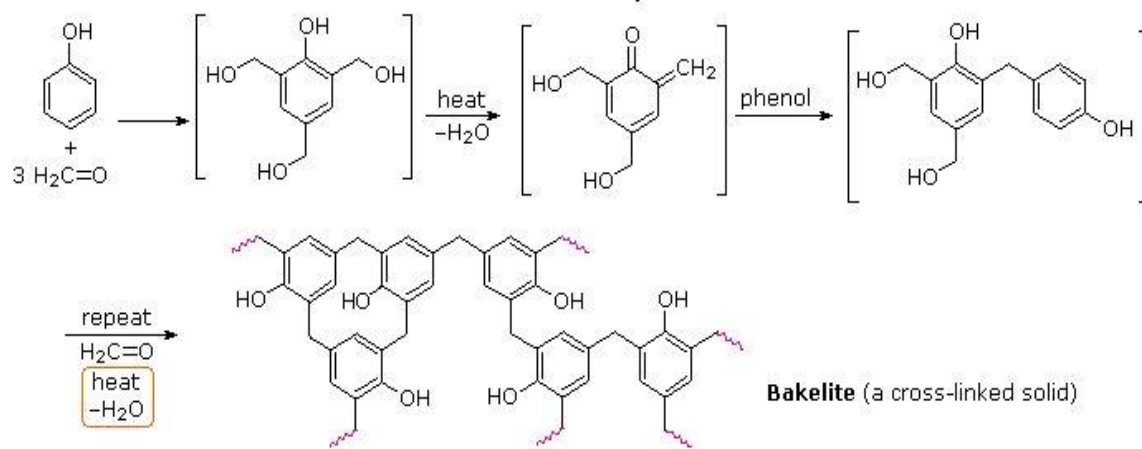
- High mechanical strength, stiffness, hardness and toughness.
- Good fatigue resistance.
- High mechanical damping ability.
- Good sliding properties.

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- Excellent wear resistance
- Good electrical insulating properties
- Good resistance to high energy radiation (gamma & x-ray).
- Good machinability.

Uses - Nylon 66 is frequently used when high mechanical strength, rigidity, good stability under heat and/or chemical resistance are required. It is used in fibers for textiles and carpets and molded parts.

2. **Bakelite** - Bakelite is a polymer made up of the monomers phenol and formaldehyde. This phenol-formaldehyde resin is a thermosetting polymer.



Some important properties of bakelite are listed below.

- It can be quickly molded.
- Very smooth molding can be obtained from this polymer.
- Bakelite moldings are heat-resistant and scratch-resistant.
- They are also resistant to several destructive solvents.
- Owing to its low electrical conductivity, bakelite is resistant to electric current.

Uses of Bakelite

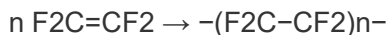
Now coming to the uses of Bakelite, since this element has a low electrical conductivity and high heat resistance it can be used in manufacturing electrical switches and machine parts of electrical systems. It is a thermosetting polymer and Bakelite has high strength meaning it basically retains its form even after extensive molding. Phenolic resins are also extensively used as adhesives and binding agents. They are further used for protective purposes as well as in the coating industry.

Further, Bakelite has been used for making the handles of a variety of utensils. It is one of the most common and important polymers that are used to make different parts of many objects.

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3. Teflon - Teflon is a name we have been used to hear from our childhood as it is an important element used in nonstick cookware utensils. Teflon is actually made of a chemical compound named polytetrafluoroethylene (PTFE) which is a synthetic fluoropolymer which has been under use for various purposes.

The chemical compound is produced by tetrafluoroethylene undergoing free radical polymerization. The equation for the process is



Properties –

- a) Hard and tough
- b) Bad conductor of electricity
- c) Resistant to heat and acid
- d) Thermally stable up to 598K

Uses

- a) For non stick cookware
- b) For seals and gaskets
- c) For providing insulation for high frequency electric installations

Plastics

Plastic is material consisting of any of a wide range of synthetic or semi-synthetic organic compounds that are malleable and so can be molded into solid objects.

Plasticity is the general property of all materials which can deform irreversibly without breaking but, in the class of moldable polymers, this occurs to such a degree that their actual name derives from this specific ability.

Plastics are typically organic polymers of high molecular mass and often contain other substances. They are usually synthetic, most commonly derived from petrochemicals, however, an array of variants are made from renewable materials such as polylactic acid from corn or cellulose from cotton linters.

Thermosetting Plastics

Thermosetting plastics are made up from long chains of molecules that are cross-linked. They have a very rigid structure.

Once set they cannot be reheated since they are permanently set. **Examples of thermosetting polymers** include:

- Vulcanized rubber
- Bakelite
- Polyurethane
- Epoxy resin

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- Vinyl ester resin

Thermo plastic

A thermoplastic is a material, usually a plastic polymer, which becomes soft when heated and hard when cooled. Thermoplastic materials can be cooled and heated several times without any change in their chemistry or mechanical properties. When thermoplastics are heated to their melting point, they melt to a liquid.

Some **examples of thermoplastics** are listed below.

- Polystyrene
- Teflon
- Acrylic
- Nylon

Difference Between Thermoplastic and Thermosetting Plastic	
Thermoplastic	Thermosetting Plastic
Thermoplastic can be synthesized by the process called addition polymerization.	Thermosetting plastics are synthesized by condensation polymerization.
Thermoplastic is processed by injection moulding, extrusion process, blow moulding, thermoforming process, and rotational moulding.	Thermosetting Plastic is processed by compression moulding, reaction injection moulding.
Thermoplastics have secondary bonds between molecular chains.	Thermosetting plastics have primary bonds between molecular chains and held together by strong cross-links.
Thermoplastics have low melting points and low tensile strength.	Thermosetting plastics have high melting points and tensile strength.
Thermoplastic is lower in molecular weight, compared to thermosetting plastic.	Thermosetting Plastic is high in molecular weight.
They soften on heating	They do not soften on heating
They are soft weak and less brittle	Hard strong and more brittle

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Applications of plastics and polymers in daily life

Polymers are used to make electronic components, paint, plastic bottles, sunglass lenses, DVDs and so much more. For instance, poly(vinyl chloride) is a strong, corrosion-resistant polymer commonly used in plumbing applications, whereas polyethylene is an example of a flexible polymer found in plastic bags.

The polymer called Polyethylene is used in plastic bags and film wraps. Polyvinyl Chloride (PVC) is used in siding, pipes, flooring purposes. The synthetic polymer Polystyrene is used in cabinets, petri dishes, CD cases, plastic cutlery and in packaging. Polyvinyl acetate is used in adhesives and latex paints.

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TYPES OF WATER:

Water is classified two types based on the behavior with soap. These are:

Soft water:

The water which forms lather with soap easily is called soft water. It contains no dissolved salts in it .Example Rain water, distilled water, demineralized water.

Hard water:

The water which not forms lather with soap easily is called hard water. It contains dissolved salts of anions like SO_4^{2-} , CO_3^{2-} , HCO_3^- with calcium and magnesium in it. Tap water, river water, spring water, sea water are some of the examples of hard water.

Causes of hardness of water:

Hardness of water is caused by the presence of soluble salt of calcium and magnesium that is bicarbonates, chlorides, sulfate of calcium and magnesium. Action of hard water on soap: When hard water is added with the potassium and sodium salt of fatty acids (soap), calcium and magnesium ions of hard water react with soap and forms insoluble curd of fatty acids. So lots of soap is wasted and hard water is not considered suitable for washing purposes.

TYPES OF HARDNESS:

Hardness of water is of two types: Temporary hardness &Permanent hardness

Temporary hardness of water:

The hardness of water which can be simply removed by boiling the water is known as temporary hardness.

Cause of Temporary hardness:

Temporary hardness is due to the presence of bicarbonates of calcium and magnesium. This type of hardness is removed by boiling the water.

Permanent hardness of water:

The hardness of water which cannot be removed by simple boiling the water is called permanent hardness.

Cause of Permanent hardness:

Permanent hardness of water is due to the presence of chlorides and sulfates of calcium and magnesium. This type of hardness is removed by washing soda process. In commercial scale, temporary hardness is removed by Clarke's process.

UNITS OF HARDNESS OF WATER:

The hardness of water is caused by the presence of soluble bicarbonates (HCO_3^-), chlorides (Cl^-), sulfate (SO_4^{2-}) of calcium (Ca^{2+}) and magnesium (Mg^{2+}). But hardness of water is measured in terms CaCO_3 equivalents of these hardness causing substances.

Degree of hardness in ppm (parts per million):

The number of parts by mass of hardness causing substances in terms of CaCO_3 present per million (10⁶) parts by mass of water is called parts per million (ppm). These concentrations are very low and practically assume the density of water unchanged that is 1 g/mL. Thus, it can be expressed as 1 parts per million = 1 ppm = 1 mg/L. Example: If hardness of water is 200 ppm, it means hardness of water in terms of CaCO_3 is 200 parts by mass in 10⁶ parts by mass of water. ppm is also termed as mg/L.

DISADVANTAGES OF USING HARD WATER IN BOILER:

In industries, water is largely used in boiler for generation of steam. Hard water if used in boiler gives rise to following defects:

- i) Formation of scale and sludge
- ii) Corrosion
- iii) Caustic embitterment
- iv) Priming and foaming.

Scale and Sludge formation:

Scale: The hard, adherent and thick layer (crust) formed on the inner walls of boiler is called Scale.

Sludge: The soft, loose and thin layer (crust) formed on the inner walls of boiler is called Sludge.

Disadvantages of scale and sludge formation:

Wastage of Fuel: Scale and sludge are bad conductors of heat, so rate of transfer of heat from boiler walls to water decrease which results wastage of fuel.

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Decrease in efficiency of boiler: Due to the formation of scale and sludge the area of cross section of boiler pipes decreases, so rate of formation of steam decreases i.e efficiency of boiler decrease.

Chances of explosion increase: If water enters in cracks of scale and sludge and formation of steam develop huge pressure, then chances of explosion will increases.

Shorten boiler life: Scale and sludge are bad conductors of heat, so rate of transfer of heat from boiler walls to water decrease and overheating of boiler pipes to maintain the steady supply of steam. Due to overheating of boiler pipes, it becomes weak.

Corrosion:

The slow and continuous eating of boiler pipes of boiler is called corrosion.
Disadvantages of corrosion:

- Corrosion decreases the life of the boiler.
- The cost of repair and maintenance of boiler increases.
- Chances of leakage of boiler pipes from joints and rivets increase.

Caustic embitterment:

The leaking (cracking) of boiler pipes and plates from joints and rivets when it becomes brittle due to the presence of alkaline substances in boiler feed water is called caustic embitterment. Disadvantages of caustic embitterment:

- i) Caustic embitterment decreases the boiler life.
- ii) The cost of repair and maintenance of boiler increase.
- iii) Efficiency of boiler decreases due to leakage.

QUALITY OF DRINKING (POTABLE) WATER:

The drinking (potable) water should satisfy the following characteristics:

1. Drinking water should be soft.
2. It should be colorless.
3. It should be odourless.
4. The pH of drinking water should be 6.9 to 8.5.
5. It should be free from disease- producing micro-organisms.

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6. The hardness of drinking water should not be more than 200 mg /L or 200ppm.
7. The alkalinity of drinking water should not be greater than 200ppm or 200 mg/L.
8. It's TDS (total dissolved solid) should not be greater than 500ppm.
9. It should not be turbid.
10. It should not contain suspended impurities.
11. It should not contain impurities of heavy metals.
12. It should be tasteless.