

MODULE 5: Corrosion Science and E-waste Management (8 Hrs)

Corrosion Chemistry: Introduction, electrochemical theory of corrosion, types of corrosion, differential metal corrosion in electronic circuits and differential aeration corrosion- waterline and pitting corrosion. Corrosion control- galvanization, anodization, cathodic protection and impressed current method. Corrosion penetration rate (CPR) - definition, importance and weight loss method-numerical problems.

Metal Finishing: Introduction, technological importance of metal finishing, difference between electroplating & electroless plating, electroplating of chromium for hard and decorative coatings, electroless plating of copper on PCBs.

E-waste: Introduction, sources of e-waste, need of e-waste management & effects of e-waste on environment and human health. Extraction of gold from e-waste from bioleaching method.

Corrosion is the primary means by which metals deteriorate. Corrosion destroys the beauty and luster of the metal and shortens its life. Corrosion once thought a problem concerned with only metallurgies and chemists is now a field of inter disciplinary study as metals are universal in their usage.

Most metals corrode on contact with water (and moisture in the air), acids, bases, salts, oils, aggressive metal polishes, and other solid and liquid chemicals. Metals will also corrode when exposed to gaseous materials like acid vapors, ammonia gas, and sulfur containing gases. Corrosion processes are usually electrochemical in nature, having the essential features of a battery.

Corrosion can be defined as “**Destruction of metals or alloys through oxidation of metals and consequent loss through chemical or electrochemical attack from the environment.**”

The process of corrosion in reality is the transformation of pure metal into its undesired metallic compounds usually oxides in the presence of suitable electrolyte. It is the reverse process of metallurgy. The familiar examples of corrosion include rusting of iron, tarnishing of silver etc. Study of corrosion becomes important because corrosion causes economic loss, destruction of resources, pollution and potential hazards.

Corrosion can be classified as:

a. Dry corrosion (chemical corrosion):

This involves direct attack of metals by corrosive gases such as carbon dioxide, Sulphur dioxide, ammonia, hydrogen chloride etc. present in the corrosion environment. Since this is observed in the absence of moisture or conducting electrolyte, it is called dry corrosion.

b. Wet Corrosion or Electrochemical corrosion or Immersed corrosion:

The corrosion of the metal takes place through the ionic reaction in the presence of moisture or electrolytes is called wet corrosion. *Ex.* Dry chlorine is non-corrosive to steel but moist chlorine leads to corrosion.

Why metals corrode; Cause for corrosion?

Pure metals are relatively at higher energy state compared to their compounds which leads to instability. Environment containing moisture acts like an electrolyte causing the electronation reaction to occur. Metals undergo oxidation ($M \rightarrow M^+ + e^-$) and this is facilitated by suitable electron acceptor in the environment. As the free energy of pure metal is higher than low energy metal oxide, metals have strong tendency to return to its native low energy oxide state. When two metals having different energy levels or potentials are coupled together, current will flow which causes the corrosion. The direction of positive current flow will be from the metal with the more negative potential to that which is more positive. Corrosion will occur at the point where positive current leaves the metal surface.

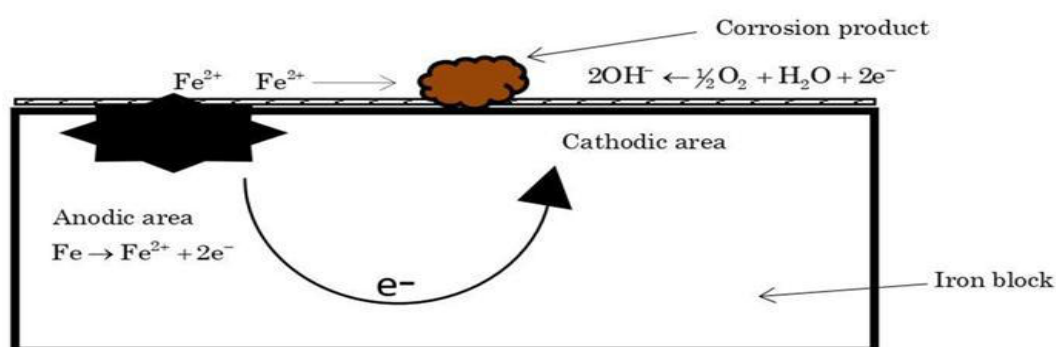
Electrochemical theory of corrosion [Theory or Mechanism of rusting of iron]:

1. According to this theory, corrosion occurs when the metal comes in contact with a conducting liquid or when two dissimilar metals are immersed or dipped partly in a solution.
2. The corrosion reactions are similar to those that occur in a galvanic cell. There is the formation of a galvanic cell on the surface of metals. Some parts of the metal surface act as anode and rest act as cathode which leads to the redox reaction.
3. Oxidation occurs at anode liberating electrons which flow to cathode where reduction occurs.
4. An aqueous media is required over the surface of metal for the conduction of ions and completion of an electrochemical circuit between an anode and cathode.
5. The electrons liberated at the anodic region migrate to the cathodic region constituting corrosion current.

6. When a metal like iron is exposed to atmosphere (air and aqueous media), the following electrochemical changes take place leading to corrosion of iron.

- Formation of large number of minute galvanic cells on the surface of metal.
- That is, large numbers of minute anodic and cathodic areas are formed on the surface.

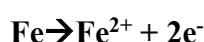
For example, metals react in the acidic environment and are dissolved (undergo corrosion) to release H_2 gas. All metals above hydrogen in electrochemical series can show this type of corrosion.



Electrochemical corrosion of iron

a. Anodic reaction (i.e., at anodic area)

Oxidation of metal takes place resulting in the corrosion of iron.



b. Cathodic reaction

Cathodic reaction consumes electrons with either by

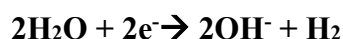
(a) Evolution of Hydrogen (b) Absorption of oxygen depending on the nature of environment.

Evolution of Hydrogen: Evolution of Hydrogen takes place in the absence of oxygen as shown below

i. In acidic medium and in the absence of oxygen the reaction is,

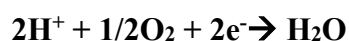


ii. In neutral or alkaline medium and in the absence of oxygen, hydroxide ions are formed with simultaneous liberation of hydrogen.

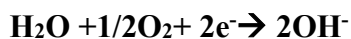


Absorption of Oxygen: absorption of oxygen takes place in the presence of oxygen.

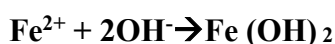
i. In acidic medium and in the presence of oxygen.



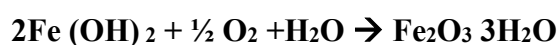
ii. In neutral or alkaline medium and in the presence of oxygen. Hydroxide ions are formed by the following reaction.



Corrosion of iron produces Fe^{2+} ions and OH^- ions at the anode and cathode sites respectively these ions diffuse towards each other, since smaller Fe^{2+} ions diffuse more rapidly than OH^- ions their combination forms insoluble $\text{Fe}(\text{OH})_2$



In oxidizing environment, it is oxidized to ferric oxide and yellow rust is hydrated ferric oxide.



At anodic area, iron is oxidized liberating electrons and ferrous ion. The electrons released at anodic area move to the cathodic area through the metal. At cathodic area, chemical species present on the surface of the metal get reduced. Cathodic area of metal just provides the surface for reduction and that itself does not undergo corrosion and remains unaffected. Depending on the environment to which metal is exposed, there are three possible reduction reactions that can occur at cathodic area.

Types of Corrosion

Differential metal corrosion in electronic circuits

When two metals with different electrochemical potentials or with different tendencies to corrode are in metal-to-metal contact in a corrosive electrolyte. Galvanic corrosion occurs when three conditions are satisfied.

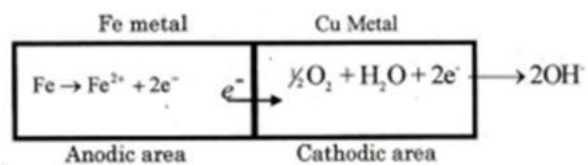
- ✓ **Two dissimilar metals:** The metals must have different electrochemical potentials.
- ✓ **Electrical contact:** The metals must be in direct contact, allowing electron flow.
- ✓ **Electrolyte:** A conductive medium (like water or saltwater) is needed to facilitate the flow of ions and electrons.

Here, the more negative (more active) metal will be the anode of the galvanic corrosion cell and its corrosion rate will be more and the more positive (more noble) metal will be the cathode and its corrosion rate will be less. The rate of differential metal corrosion depends upon the amount of current passing from the anode to the cathode, that is, on the difference in the potentials; higher the difference faster is the rate of corrosion. This type of corrosion is usually seen at the joint between the dissimilar metals. When aluminum alloys are in contact with

stainless steel, if galvanic corrosion occurs, corrosion of aluminium is accelerated. Galvanic corrosion is the principle behind the construction of dry cell.

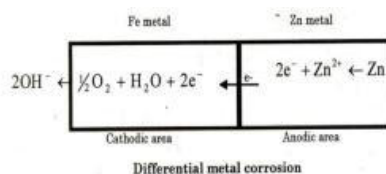
Differential metal corrosion, also known as galvanic corrosion, occurs in electronic circuits when two dissimilar metals are in contact with an electrolyte (like moisture or condensation), causing the more reactive metal (anode) to corrode while the less reactive metal (cathode) is protected. The rate of corrosion is determined by the potential difference between the two metals; a larger difference accelerates the attack on the anode. This process leads to accelerated failure as the anode dissolves and corrosion products form, potentially disrupting the circuit. Two different metals, such as a steel screw and a copper component, are electrically connected and come into contact with an electrolyte.

E.g. Solder joints: Using different solders or connecting different metals, like a lead-based solder on a copper wire, can create galvanic cells.



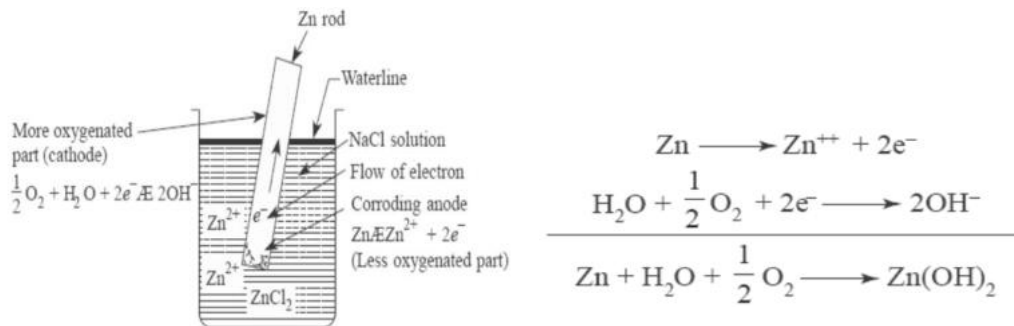
Standard electrode potential of Fe (-0.44 V) is less than that of Cu (0.34 V). Therefore, when iron is in contact with copper, iron becomes anodic and undergoes corrosion, whereas copper becomes cathodic and remains unaffected.

Similarly, standard electrode. potential of Zn (-0.76 V) is less than that of Fe (-0.44 V). Therefore, when iron is in contact with zinc, zn becomes anodic and undergoes corrosion. Fe becomes cathodic and remains unaffected. When zinc comes in contact with iron following reactions occur.



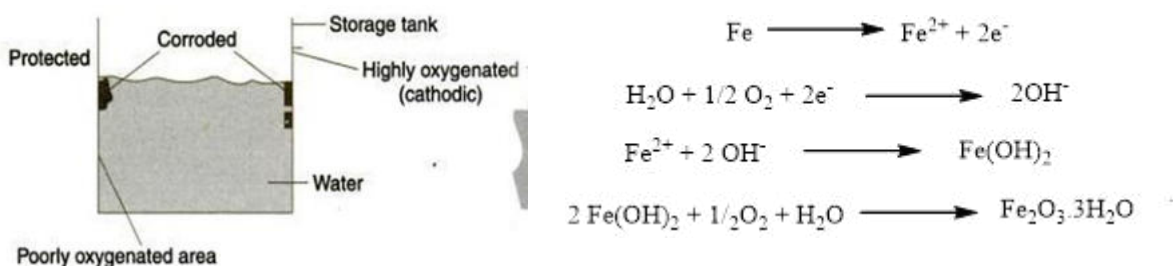
Differential aeration corrosion [Concentration cell corrosion]:

Differential aeration corrosion occurs when a metal surface is exposed to differential air concentrations or oxygen concentrations. The part of the metal exposed to higher concentration of oxygen acts as cathode and the part exposed to lower concentration of oxygen acts as anode. Consequently, the poorly oxygenated area undergoes corrosion. For example, part of the nail inside the wall, being exposed to lower oxygen concentration than the exposed part, undergoes corrosion. If a metal rod is dipped in an electrolyte, the portion dipped in water is poor in oxygen concentration and works as anode which gets corroded and the portion above water acts as cathode which is protected. The system will act as a concentration cell and the chemical reactions for zinc dipped in water are given as:



Water line corrosion

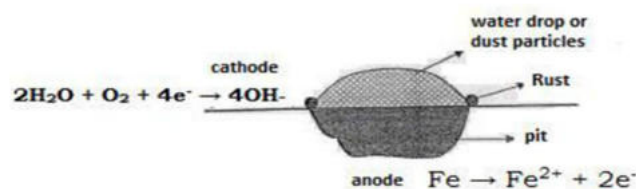
Waterline corrosion is one of the types of differential aeration corrosion is more prevalent in ocean going ships, water storage steel tanks, etc., in which a portion of the metal is under water. The water line corrosion takes place due to the formation of differential oxygen concentration cells. The part of the metal below water line is exposed only to dissolved oxygen while the part above the water is exposed to higher oxygen concentration of the atmosphere. Thus, part of the metal below the water acts as anode and undergoes corrosion and the part above water line is free from corrosion.



Pitting corrosion

In pitting corrosion, local galvanic cell is formed because of crack on the surface of a metal, chemical attack, local straining of metal sliding under load. The crack portion acts as anode and rest of the metal surface acts as cathode. Anodic area will be corroded and the formation of a pit is observed. This type of corrosion is thus called pitting corrosion. External impurities such as sand, scale, dust embedded on the surface of metals lead to pitting. Corrosion of aluminium and stainless steel in chloride solution causes pitting.

Pitting corrosion is a localized form of corrosion by which cavities or "holes" are produced in the material. When a large drop of water or an electrolyte or dust particles are placed on the surface of a clean sheet of iron, the concentration of oxygen will be less at the bottom of the drop and becomes anode, while oxygen will be more at the surface area and becomes cathode. In the presence of electrolyte and moisture, corrosion starts at the bottom of the drop causing pits or cavities at the bottom. Once a pit is formed, the corrosion progresses rapidly. This is because of the formation of a small anodic area (pit) compared to a large cathodic area (surface). The latter induces the small anodic area to corrode faster by accepting electrons from the anodic area.

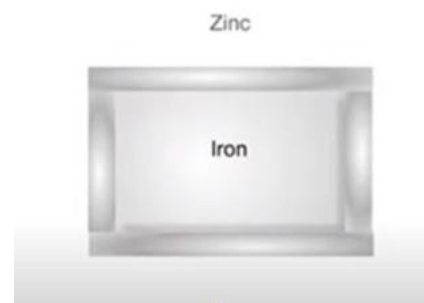
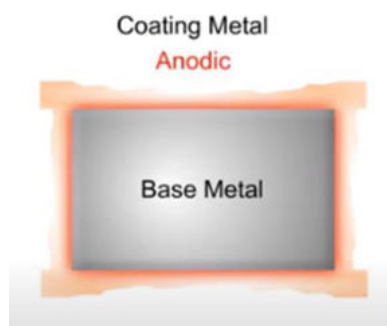
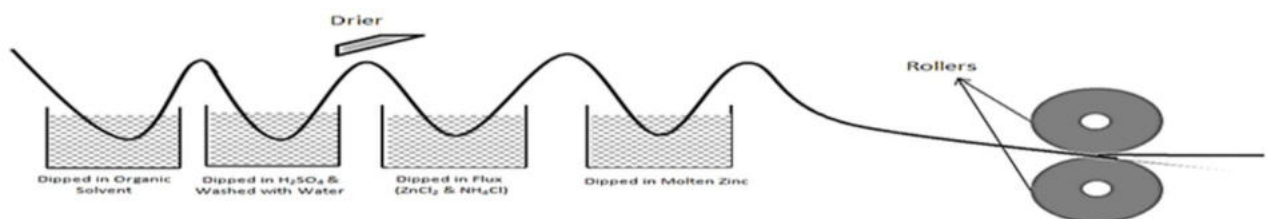


Corrosion control methods

Galvanization: Galvanization is typically achieved through a hot-dip galvanizing process, where the metal like iron is immersed in molten zinc, allowing the zinc to bond with the surface of the metal. When steel or iron is exposed to moisture and oxygen, it can undergo a chemical reaction known as oxidation, leading to rust formation. By applying a layer of zinc through galvanization, the zinc acts as a sacrificial anode, corroding instead of the underlying metal. It effectively prevents rust from forming and extends the lifespan of the coated material. The reason is zinc has standard reduction potential of -0.76 V which is less than that of iron (-0.44 V) so zinc has more tendency to lose electrons compared to iron.

Hot dipping galvanization

1. Galvanization or galvanization (or galvanizing as it is most commonly called) is the process of applying a protective zinc coating to iron or steel, to prevent rusting. The most common method is hot dip galvanizing, in which steel sections are submerged in a bath of molten zinc.
2. The hot-dip galvanizing process involves three primary stages: surface preparation, galvanization, and post-treatment
3. Articles to be galvanized are dipped in organic solvent or alkaline solution to remove dust or grease.
4. Then dipped in dilute sulphuric acid to remove any rust formed. This is called acid pickling after which it is washed with water and dried.
5. Then dipped in solution of zinc chloride (ZnCl_2) and ammonium chloride (NH_4Cl) which acts as a flux to have firm coating.
6. Then dipped in molten zinc at 430°C and excess of zinc is removed by rolling over rollers
7. The article is dried using hot air dryer
8. More number of layers of zinc can be developed by repeating the procedure



Galvanized steel products like structures, wire fences, and pipes are widely used in outdoor, agricultural, residential, and industrial applications because of their strength and durability.

Anodizing: Anodized oxide coatings [Non-Ferrous method]

Anodizing is an electrochemical process that converts the metal surface into a decorative, durable, corrosion-resistant, anodic oxide finish. In simple words, Anodizing is an electrolytic passivation process used to increase the thickness of the natural oxide layer on the surface of metal parts. Aluminum is ideally suited to anodizing, although other nonferrous metals, such as magnesium and titanium, also can be anodized. Metals like Al, Zn and Mg are made to develop protective metal oxide coating artificially on their surfaces.

In anodizing process, the aluminium surface needs to be cleaned thoroughly to remove any dirt, grease, or other contaminants. The pre-treatment process includes the following steps:

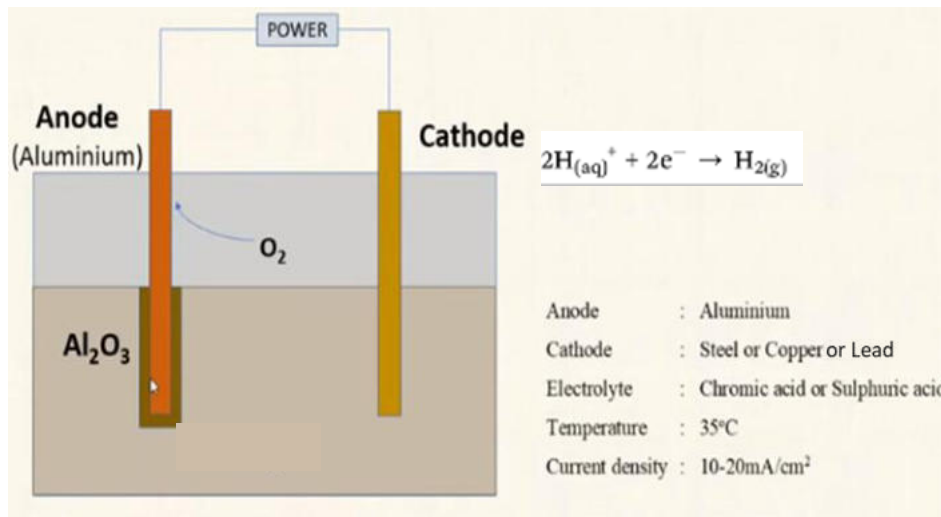
Degreasing: The aluminium parts are immersed in a hot alkaline solution to remove any oil or grease on the surface.

Etching: The aluminium surface is treated with an acidic solution to create a microscopically rough texture that helps the anodizing solution to penetrate the metal.

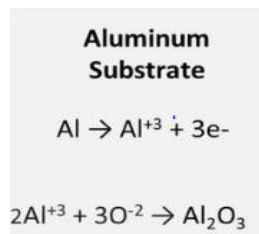
Desmutting: The aluminium parts are rinsed in a solution to remove any remaining smut or etching residue.

1. In anodized coating, the base metal is made up of *anode* and inert metal like *lead* (less active than Aluminium) is made *cathode*.
2. Anodizing is accomplished by immersing the aluminum into an acid electrolyte bath and passing an electric current through the medium.
3. A cathode is mounted to the inside of the anodizing tank .
4. The aluminum acts as an anode, so that oxygen ions are released from the electrolyte to combine with the aluminum to form Aluminium oxide on the surface of Aluminium
5. The anodic oxide structure originates from the aluminum substrate and is composed entirely of aluminum oxide.
6. This aluminum oxide is not applied to the surface like paint or plating, but is fully integrated with the underlying aluminum substrate, so it cannot chip or peel.

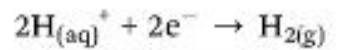
- It has a highly ordered, porous structure that allows for secondary processes such as coloring and sealing.
- Anodizing is, therefore, a matter of highly controlled oxidation the enhancement of a naturally occurring phenomenon.



At anode,

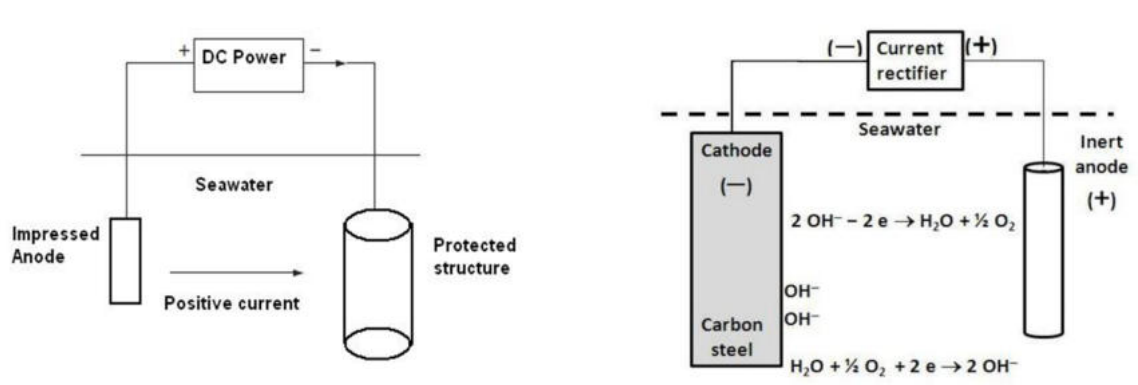


At cathode,



Impressed Current Method for the Prevention of Corrosion

- The impressed current method is a cathodic protection technique used to prevent corrosion of metal structures.
- In this method, an external DC power source (like a rectifier) supplies current to the metal that needs protection, making it act as a cathode in an electrochemical cell.
- This current counteracts the natural corrosion current, preventing the structure from corroding. Since cathodes do not corrode, the metal is protected from oxidation.
- To complete the circuit, inert external anodes (graphite, platinum, mixed metal oxides, etc.) are buried or immersed in the surrounding environment (soil or seawater).
- The applied current forces electrons onto the metal surface and prevents it from losing metal ions.



Anode: Graphite/platinum (+)
Cathode: Metal to be protected (-)
Power source: DC rectifier

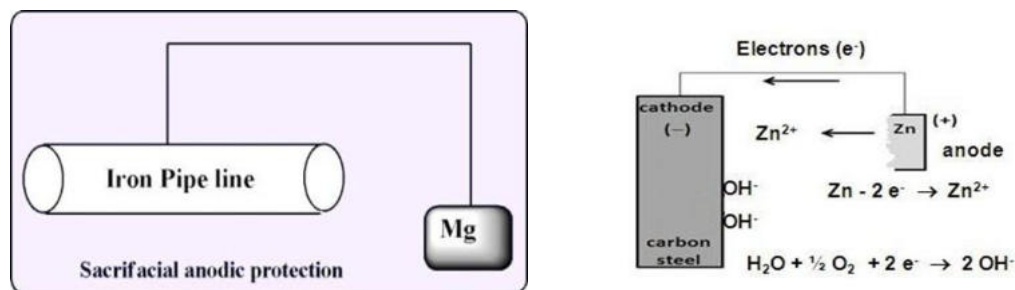
Anodized material is widely used in construction, architecture, home appliances, food-processing equipment, and furniture manufacturing. It is also used to produce sporting goods, boats, motor-vehicle components, jewellery, and artwork.

Sacrificial anode method

1. It is a technique of protecting a metal from corrosion by converting it to a cathode. Metal to be protected is converted into a cathode by connecting it to a more active metal.
2. The active metal acts as anode. The more active metal itself gets corroded slowly while the parent structure (cathodic) is protected.
3. The materials used for sacrificial anodes are either relatively pure active metals, such as zinc or magnesium, or are magnesium or aluminum alloys that have been specifically developed for use as sacrificial anodes.
4. At anode Zn is oxidized to Zn^{2+} giving electrons.
5. Metallic blocks of Al, zinc, or Mg are connected to the metallic structure of iron to be protected. Since the anode is sacrificed to prevent the corrosion of the Cathode, it is called the sacrificial anode method.
6. Metal in seawater is one such example with the iron metal coming into contact with electrolytes.
7. Under normal circumstances, the iron metal would react with the electrolytes and begin to corrode, growing weaker in structure and disintegrating.

8. The addition of zinc, a sacrificial anode, would prevent the iron metal from "corroding". According to the table of Standard Reduction Potentials, the standard reduction potential of zinc is about -0.76 volts.
9. The standard reduction potential of iron is about -0.44 volts. This difference in reduction potential means that Zinc would oxidize much faster than iron would. In fact, zinc would oxidize completely before iron would begin to reaction.

Example 1: When Magnesium blocks are connected to the sides of the ship, it acts as an anode and prevents the ship from corrosion. Magnesium blocks are connected to buried pipelines to prevent the structure from corrosion, by acting as an anode.



Sacrificial Anodes are used to protect the hulls of ships, water heaters, pipelines, distribution systems, above-ground tanks, underground tanks, and refineries. The anodes in sacrificial anode cathodic protection systems must be periodically inspected and replaced when consumed.

Corrosion penetration rate

Corrosion Penetration Rate (CPR) is defined in three ways:

- (1) The speed at which any metal in a specific environment deteriorates due to a chemical reaction in the metal when it is exposed to a corrosive environment
- (2) The amount of corrosion lost per year in thickness
- (3) The speed at which corrosion spreads to the inner portions of a material.

The CPR is calculated as follows:

$$\text{CPR} = (k \times W) / (D \times A \times T)$$

where k = a constant

W = total weight lost

T = time taken for the loss of metal

A = the surface area of the exposed metal

D = the metal density in g/cm³

$CPR = \frac{K \times W}{D \times A \times T}$			
Parameter	Significance	Unit	
CPR	Corrosion Penetration Ratio	mm/y	mpy
K	A constant	87.6	534
W	Total weight lost by the metal	mg	mg
D	Density of metal	g/cm ³	g/cm ³
A	Surface area of the exposed metal	cm ²	inch ²
T	Time taken for the loss of metal	hour	hour

Metal finishing

Metal finishing is the name given to all those processes employed to modify the surface properties of conducting or non-conducting materials by deposition of a layer of metal over them. A thin coating of a metal can be developed on the surface of any material either by using electric current or a suitable reducing agent. Accordingly, there are two techniques mostly used for metal finishing namely **electro plating** and **electroless plating**.

Electroplating: Plating process that involves the use of an electric current to bind the metal particles onto a surface. Electroplating can be done only on conducting materials. Non-conductive materials cannot be coated.

Electroless plating: Plating process that does *not* use an electric current to bind the metal particles onto a surface. Electroless plating can be done for both conducting & Non-conductive materials.

Technological importance of metal finishing

1. Corrosion Resistance: Metal finishing protects the base metal from oxidation and corrosion, increasing the life span of components used in harsh environments.
2. Wear and Abrasion Resistance: Improves surface hardness and wear resistance, which is essential for machine parts, tools, and industrial equipment.
3. Enhanced Appearance: Provides a smooth, shiny, and decorative finish, improving the aesthetic appeal of metal products (e.g., chrome plating, polishing).
4. Electrical Properties: Modifies electrical conductivity or resistance as needed — important in electronics, connectors, and circuit components.

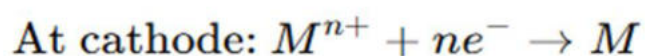
5. Improved Solderability and Adhesion: Facilitates better bonding with solder, paint, rubber, or adhesives (e.g., during vulcanization or coating processes).
6. Chemical Resistance: Protects against chemical attack from acids, alkalis, or solvents, useful in chemical processing equipment.
7. Reflectivity and Optical Properties:
Enhances reflectivity in mirrors, optical instruments, and decorative items.
8. Reduction of Friction: Provides lubrication-like properties or smoother surfaces, improving energy efficiency in moving parts.
9. Economic Benefits: Extends product life, reduces maintenance costs, and enhances performance, making manufacturing more cost-effective.

Electroplating

Coating a layer of metal over the surface of another metal, alloy, or any other conducting material by applying an electric current is called electroplating. By this method, any conducting material can be coated with a thin and uniform layer of another metal.

Process of Electroplating

1. Electroplating is carried out in a device called an electrolytic cell which consists of two electrodes.
2. The material to be coated is taken as the cathode (connected to the negative terminal) and the anode is connected to the positive terminal.
3. Both electrodes are dipped in an electrolyte solution containing ions of the coating metal.
4. When direct current (DC) passes through the solution cations (metal ions) move toward the cathode, where they gain electrons and are reduced to metal atoms. This metal atoms get deposited on the cathode surface, forming the coating.
5. **Cations (metal ions)** move toward the **cathode**, where they gain electrons and are reduced to metal atoms. This metal atoms get deposited on the cathode surface, forming the coating.



6. **Anions** move toward the **anode**, where they get oxidized.



If the anode is dissolvable, it provides metal ions to the solution (its thickness decreases over time). If the anode is inert, only electrolyte components react, and the electrolyte must be replenished to maintain ion concentration. This entire process — decomposition of an electrolyte by passing an electric current — is known as electrolysis.

Electroplating of Chromium

- ✓ Chromium electroplating is the process of depositing a thin layer of chromium metal on another metal surface (usually steel, nickel, or copper) using an electric current. It provides a bright, hard, and corrosion-resistant coating. The purpose of electroplating is
1. To improve **appearance** (decorative finish — shiny and reflective surface)
 2. To increase **corrosion resistance**
 3. To improve **hardness** and **wear resistance**
 4. To reduce **friction** on moving parts

There are two types of chromium coatings:

1) Decorative Chromium Coatings:

Decorative chromium deposit is the coating of thin layer of chromium with thickness of 0.25 to 0.75 μm . Thicker deposits look very dull. Decorative chromium coatings exhibit excellent tarnish, corrosion resistance, with appealing colour and high optical reflectivity.

Applications:

These coatings are used to impart bright and decorative look to materials like automotive bumps, wheel rims, taps, handles etc.

2) Hard Chromium Coatings:

Deposition of chromium with a thickness of 0.005 to 0.75 mm is referred to as hard chrome coating. Hard chromium coatings exhibit good surface hardness, excellent tarnish, corrosion, wear, and scratch resistance.

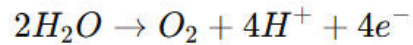
Applications:

These coatings are used mainly to impart surface hardness and wear resistance to materials like

in cutting edges of milling and drilling tools, hand guns, aircraft landing parts, axels, cylinder linings, piston rings etc.

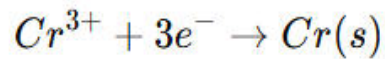
At Anode (Oxidation reaction):

Water molecules are oxidized to oxygen gas. Lead anode does not dissolve—it remains inert



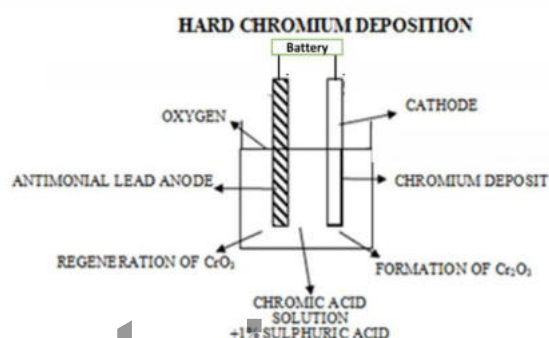
At Cathode (Reduction reaction):

Chromium ions are reduced to metallic chromium and deposited on the cathode surface.



Here, the trivalent chromium ions (Cr^{3+}) come from the reduction of chromic acid during the process. The oxygen gas is liberated at the anode surface.

Component	Role / Function
Cathode	Metal to be plated
Anode	Lead (inert) or alloy Pb-Sb
Electrolyte	Chromic acid + sulphuric acid
Temp	45–55°C
Current Density	20–60 A/dm ²
Purpose	Corrosion resistance, hardness, appearance

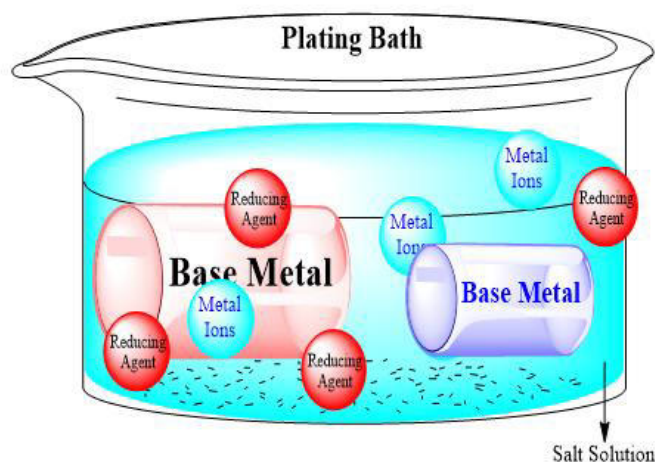
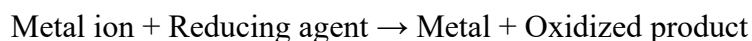


Electroless plating of copper on PCB

A printed circuit board (PCB) is a medium used in electrical and electronic engineering to connect electronic components to one another in a controlled manner. It takes the form of a laminated sandwich structure of conductive and insulating layers etched with from one or more sheet layers of copper laminated. PCB copper plating refers to the process of electroplating a thin layer of copper onto a printed circuit board (PCB) substrate. The copper layer serves as the conductive pathways or traces for the electrical current to flow.

Electroless plating: “Deposition of a metal from its salt solution on a catalytically active surface by a suitable reducing agent without using electrical energy is known as ‘electroless plating.’”

1. Electroless plating involves plating of metal ions without the use of an external source of electrical energy. It is the most extensively used electroless coating within the manufacturing industry and the most prevalent for engineering purposes.
2. The plating bath contains the salt solution along with reducing agents and other additives.
3. When a catalytically active base metal is introduced into the plating bath, the reducing agent reduces the metal ion in solution. Formed metal atoms will deposit on the active sites of the coating metal.
4. Electroless plating involves coating of noble metal like copper, silver, nickel, gold, or palladium on active metal without the use of electricity.
5. This reduced metal deposits on the base metal.
6. **Reaction:**



Steps involved in electroless plating

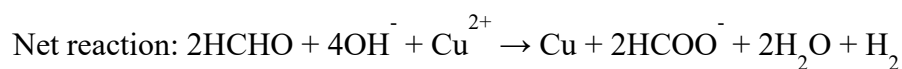
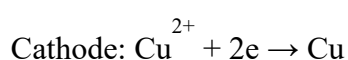
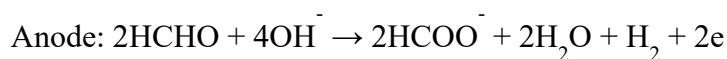
Preparation of the surface: The surface of plastic is degreased by treating with alkali solution and finally washed with distilled water. The cleaned surface is treated with SnCl_2 and PdCl_2 alternatively to obtain catalytically active surface.

Composition of electroless bath:

Coating electrolyte	CuSO_4 solution 12g/L
Reducing agent	Formaldehyde (HCHO) 8g/L
Buffer	NaOH 15g/L + Rochell's salt 14g/L (potassium sodium tartarate)
Complexing agent	EDTA 15g/L
pH	11
Temperature	25 °C

Reactions:

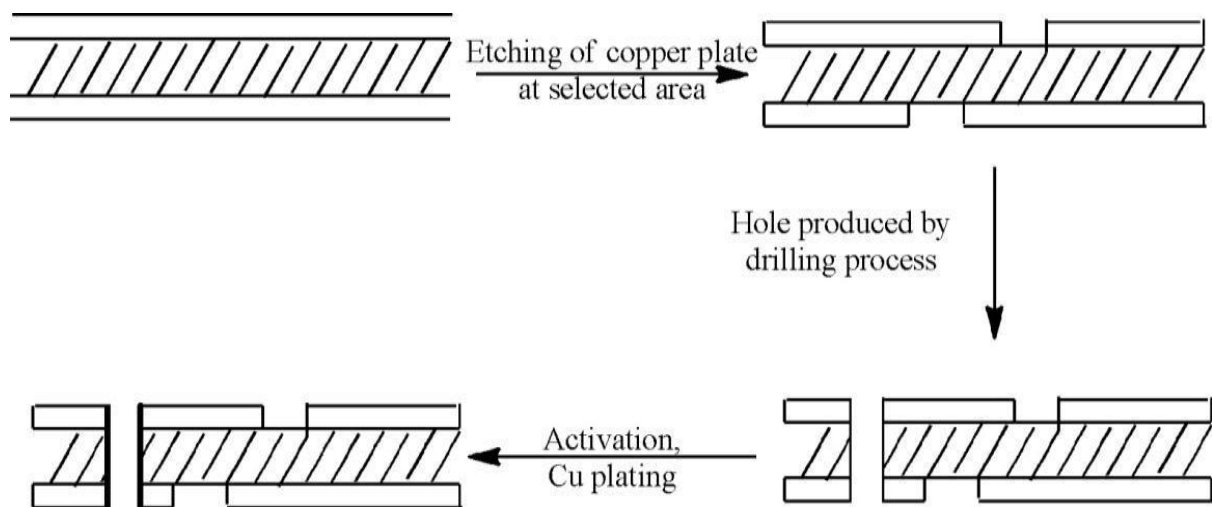
Reactions:



Manufacture of double-sided PCB by electroless plating:

1. The process starts with a base board (fiberglass or epoxy) that gives strength and insulation.
2. Thin copper layers are added on both sides of the board.
3. A light-sensitive coating (photoresist) is applied and exposed to UV light to form the circuit design.

4. The board is placed in a chemical solution to remove unwanted copper, leaving the circuit pattern.
5. Small holes are drilled to connect the two sides of the board, and the hole surfaces are prepared for metal coating.
6. Finally, copper is deposited inside the holes and on the surface using electroless copper plating, creating electrical connections between both sides.



E-waste management

“Electronic Waste or E-Waste describes rejected electrical or electronic devices. All items of electrical and electronic equipment and its parts that have been discarded by the user as waste without the purpose of re-use or re-cycle is called Electronic Waste.”

Common Items of E-Waste

Large appliances: Refrigerators, washing machines, TVs

Small appliances: Toasters, irons, hairdryers

IT equipment: Computers, laptops, mobile phones

Laboratory instruments: Microscopes, calorimeters

Lighting: Fluorescent lamps

Tools and toys: Drills, screwdrivers, sports electronics

Sources of E-waste

1. Household Sources: Electronic gadgets and appliances used in homes that become old or non-functional.

Examples: TVs, radios, music systems, Mobile phones, tablets, computers, Refrigerators, washing machines, microwaves, Air conditioners, fans, mixers, electronic toys and remote-control devices.

2. Commercial Sources: Generated from offices, shops, and business establishments.

Examples: Computers, printers, scanners, photocopiers, telecommunication devices (phones, routers, modems), office lighting, air conditioning, billing machines.

3. Industrial Sources

E-waste from industrial automation and control systems.

Examples: Process control equipment, industrial robots, Large servers, UPS units, Power generation and transmission electronics

4. Institutional Sources

Generated from schools, colleges, hospitals, and research centers.

Examples: Laboratory and computer equipment, medical instruments (X-ray, ECG, MRI), Educational multimedia devices (projectors, smart boards)

5. Government and Military Sources

Outdated or obsolete electronic devices from public departments and defense sectors.

Examples: Communication and radar systems, surveillance devices and control panels, old computer networks, data storage systems

Need for E-Waste Management

E-waste management is essential due to the rapid increase in electronic device usage and disposal. It ensures environmental protection, resource recovery, and public health safety.

1. Environmental Protection: Toxic materials like lead, mercury, cadmium, and chromium are present in e-waste. If disposed improperly, these chemicals leach into soil and water, causing long-term pollution. Proper management reduces environmental contamination.

2. Human Health Safety: Exposure to e-waste toxins can cause neurological, respiratory, and reproductive health problems. Informal recycling methods (burning, acid leaching) release

harmful fumes, affecting workers and nearby residents. Safe handling and recycling protect human health.

3. Conservation of Resources: Electronic devices contain valuable metals like gold, silver, copper, and palladium. Recycling e-waste helps recover and reuse these resources, reducing the need for mining. This leads to sustainable resource utilization.

4. Energy Conservation: Recycling old electronics uses less energy than extracting and processing new raw materials. Efficient e-waste management therefore saves energy and reduces carbon emissions.

5. Legal and Ethical Responsibility: Many countries have e-waste management laws (e.g., India's E-Waste Management Rules, 2016). Proper disposal ensures compliance with regulations and promotes corporate social responsibility (CSR).

6. Economic Opportunities: E-waste recycling and refurbishing create new jobs and business opportunities in the green economy. Promotes circular economy principles by extending product life cycles.

Extraction of Gold from E-waste by Bio-leaching Process

Step 1: Dissolution of Cu and Au (Chemical process)

Step 2: Recovery of Gold using Cyanogenic Bacteria (Biological process)

Dissolution of Copper and Gold

1.Collection and Preparation

Collect electronic scrap materials (such as circuit boards, connectors, and electronic chips). Grind the materials finely in a vibratory cup mill.

2.Particle Size Reduction

The ground material is sieved to obtain a particle size $\leq 75 \mu\text{m}$.

3.Acid Digestion

Subject the crushed powder to acid digestion using 65% nitric acid (HNO_3). Boil the mixture until the brown gas (NO_2) is completely depleted.

4.Formation of Solutions

Copper and gold dissolve forming a Cu and Au solution. After complete digestion, a gold solution is obtained for further processing.

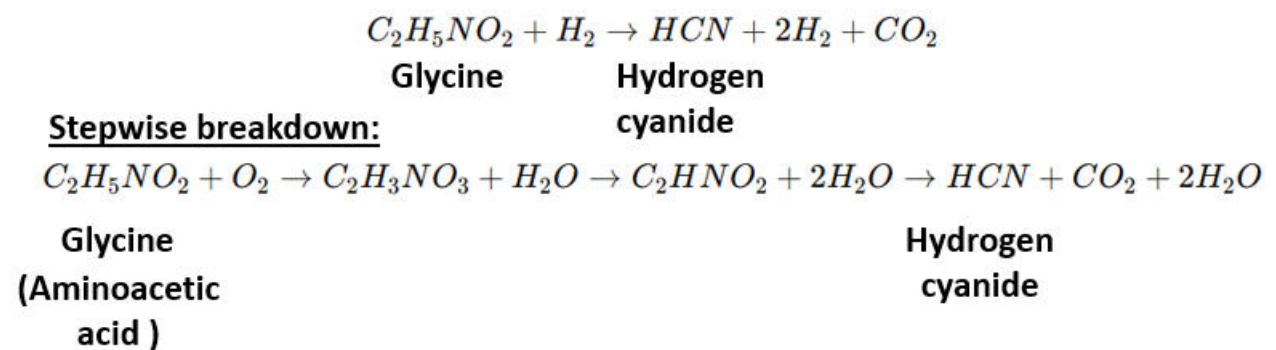
Recovery of Gold Using Cyanogenic Bacteria

Biological Principle: Certain cyanogenic bacteria such as *chromobacterium violaceum* or *Pseudomonas aeruginosa* (microorganisms capable of generating cyanide) are cultured under optimized pH, temperature, and nutrient conditions. These bacteria can metabolize glycine ($C_2H_5NO_2$) to produce hydrogen cyanide (HCN), which dissociates into cyanide ions (CN^-) that leaches gold. Here, glycine undergoes a biological oxidation in the presence of oxygen. Through multiple intermediate steps, it eventually yields hydrogen cyanide (HCN), carbon dioxide (CO_2), and water (H_2O).

Reactions Involved:

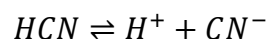
a. Cyanide Generation

The bacteria metabolize glycine through oxidation:



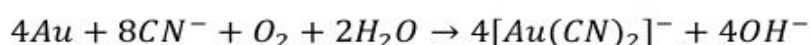
Gold Dissolution Reaction

The **hydrogen cyanide** produced reacts in solution as:



Then, **cyanide ions** (CN^-) dissolve gold as follows:

Recovery of Gold: Gold is recovered from the leachate by zinc cementation, activated carbon adsorption, or electrowinning, followed by refining to pure metal. The complex formed, $[Au(CN)_2]^-$, is water-soluble — representing **gold in leached form**.



Advantages of Bio-leaching

- Environmentally friendly (less use of toxic chemicals)
- Cost-effective for small-scale e-waste recycling
- Uses naturally occurring bacteria instead of hazardous cyanide directly

Effect of E-WASTE on human health

E-waste contains toxic substances like Lead (Pb), Mercury (Hg), Cadmium (Cd), Chromium (Cr), Arsenic (As), Copper (Cu), and Dioxins. Exposure occurs through inhalation, ingestion, and skin contact, affecting almost all major organ systems.

1.Organ System–Specific Effects

- a) **Neurological Damage:** Lead and mercury act as neurotoxins, causing developmental and cognitive impairments.
- b) **Kidney & Liver Damage:** Heavy metals accumulate in these organs, leading to dysfunction and failure.
- c) **Respiratory Problems:** Burning e-waste releases toxic fumes, leading to bronchitis, asthma, and chronic respiratory decline.
- d) **Cardiovascular & Endocrine Disorders:** Arsenic and dioxins disrupt normal hormone and heart functions.
- e) **Reproductive Problems:** Dioxins and heavy metals interfere with fertility and cause congenital disorders.
- f) **Immune System Damage:** Persistent exposure weakens immunity, making individuals prone to infections.

2. Skin and Musculoskeletal Effects

- a) Direct contact with hazardous substances leads to **rashes, burns, and skin disorders**.
- b) **Musculoskeletal pain** occurs among workers due to prolonged exposure and poor working conditions.
- c) **Chronic and Long-term Health Risks**
- d) **Cancer Risk:** Exposure to carcinogenic compounds like PCBs and heavy metals increases cancer incidence.
- e) **Thyroid Disorders:** Dioxins and other toxins disturb hormonal balance.
- f) **Hypertension and Metabolic Disorders:** Toxic metal accumulation alters lipid metabolism and increases blood pressure.

3. Vulnerable Groups: Children & Pregnant Women

- a) Children and pregnant women are most affected due to developing organs and hormonal systems.
- b) Children's exposure effects:
- c) Adverse neonatal outcomes: stillbirth, premature birth.
- d) Neurodevelopmental and behavioral issues: learning disabilities, cognitive decline due to lead exposure.
- e) Respiratory impairment: reduced lung function, higher asthma incidence from polluted air.
- f) Pregnant women risk transmitting toxins to the fetus, affecting fetal brain and organ development

4. Occupational Hazards for E-Waste Workers

- a. Workers involved in informal recycling are prone to:
- b. Altered lipid metabolism
- c. Reproductive and thyroid problems
- d. Respiratory decline or asthma
- e. Hypertension

Effect of E-waste on the environment:

E-waste can have many negative effects on the environment, including:

1.Contamination of soil, water, and air: Toxic substances like lead, mercury, and cadmium can leach into the soil and groundwater from e-waste in landfills or that's been improperly processed. These substances can also contaminate dust and air at recycling sites and in nearby communities.

2.Air pollution: Burning e-waste releases toxic fumes like dioxins and furans into the atmosphere. These fumes can degrade air quality and cause respiratory problems and other health issues.

3.Global warming: The decomposition of e-waste in landfills produces greenhouse gases, including methane and carbon dioxide, which contribute to global warming.

4.Impact on biodiversity: Toxic substances from e-waste can affect local wildlife and biodiversity. Animals and plants can absorb these hazardous chemicals, which can lead to genetic mutations and disruptions in reproductive systems.

5.Ground water is at a risk: Dismantling of substances as cathode ray tubes causes the release of heavy metals in the ground water, making it highly toxic and unsafe for consumption. Over accumulation of these toxic substances in the body can cause toxicity or poisoning.

6. Death of flora and fauna: Gold- plated compounds release hydrocarbons which are directly discharged into rivers banks. This acidifies river water, eventually resulting in the death of flora and fauna on the aquatic environment. The fact that already almost all rivers in India are facing a phenomenal level of pollution shows how far the problem stretches.
