

1. (a) Define the following:

○ (i) **Ionization Potential.**

- Ionization potential (or ionization energy) is the minimum amount of energy required to remove the most loosely bound electron from an isolated gaseous atom or ion in its ground state.
- It is typically measured in electron volts (eV) or kilojoules per mole (kJ/mol).
- The first ionization potential refers to the removal of the first electron, the second ionization potential for the second electron, and so on. Higher ionization potentials indicate a greater difficulty in removing electrons.

○ (ii) **Sulphur Smog.**

- Sulphur smog, also known as London smog or industrial smog, is a type of air pollution characterized by a high concentration of sulfur oxides (primarily sulfur dioxide, SO_2), particulate matter, and fog.
- It typically forms in cold, damp, and still atmospheric conditions, often in urban areas where there is extensive burning of sulfur-containing fossil fuels (like coal) for heating and industry.
- The sulfur dioxide reacts with water droplets and particulate matter in the atmosphere to form sulfuric acid (H_2SO_4) aerosols, which contribute to its corrosive and health-damaging effects.

○ (iii) **Solubility products.**

- The solubility product (K_{sp}) is an equilibrium constant for the dissolution of a sparingly soluble ionic compound in water.

- It represents the product of the concentrations of the constituent ions in a saturated solution, each raised to the power of its stoichiometric coefficient in the balanced dissolution equation.
- A higher K_{sp} value indicates higher solubility of the compound. It is a measure of the extent to which a sparingly soluble salt dissolves in water.
- **(iv) Electrochemical cells.**
 - Electrochemical cells are devices that convert chemical energy into electrical energy (galvanic or voltaic cells) or convert electrical energy into chemical energy (electrolytic cells) through redox reactions.
 - They consist of two half-cells, each containing an electrode immersed in an electrolyte, connected externally by a wire and internally by a salt bridge or porous barrier.
 - In galvanic cells, spontaneous redox reactions generate an electric current, while in electrolytic cells, an external electrical current drives non-spontaneous redox reactions.
- **(v) Organic carbon.**
 - Organic carbon refers to carbon atoms that are covalently bonded to other carbon atoms or to hydrogen atoms, typically found in organic compounds.
 - In environmental contexts, it refers to carbon that is part of organic matter, such as living organisms, dead plant and animal material, humus in soil, and various organic compounds in water bodies.
 - It is distinct from inorganic carbon, which is found in compounds like carbon dioxide (CO_2), carbonates (CO_3^{2-}), and bicarbonates (HCO_3^-).

(b) Fill in the blanks:

- **(i) Minamata disease is a neurological disease caused by severe poisoning of mercury.**
- **(ii) If Dissolved Oxygen levels drop below 4 mg/l, the aquatic life present experiences extreme stress.**
- **(iii) NO_x (Nitrogen oxides) gas is the major contributor to photochemical smog.**
- **(iv) Permanent hardness of water is caused by the presence of chlorides and sulfates of calcium and magnesium.**
- **(v) Dark organic matter in soil that is formed by the decomposition of plant and animal matter is called as humus.**

2. Write explanatory notes on the following (any three):

- **(i) Chelation.**
 - **Definition:** Chelation is a type of bonding in which a central metal ion (typically a cation) forms multiple coordinate covalent bonds with a single ligand molecule, known as a chelating agent or chelator. The chelating agent "grabs" or "claws" the metal ion, forming a ring-like structure called a chelate complex.
 - **Chelating Agents:** These are typically organic molecules that contain two or more donor atoms (e.g., oxygen, nitrogen, sulfur) that can bind to the metal ion. Examples include EDTA (ethylenediaminetetraacetic acid), humic acids, amino acids, and porphyrins (like chlorophyll and heme).
 - **Stability:** Chelate complexes are generally more stable than complexes formed by monodentate ligands (ligands

that bind at only one point) due to the chelate effect, which is primarily an entropic advantage.

▪ **Importance in Environment and Biology:**

- **Nutrient Availability:** Chelation plays a crucial role in making essential micronutrients (like iron, zinc, manganese) available to plants in soil, as chelators prevent them from precipitating or becoming adsorbed and thus keep them soluble.
- **Heavy Metal Detoxification:** Chelating agents are used in environmental remediation to remove toxic heavy metals from contaminated soil and water (chelation therapy).
- **Biological Systems:** Many vital biological molecules are chelates. For example, chlorophyll (in plants) has magnesium chelated by a porphyrin ring, and hemoglobin (in animals) has iron chelated by a porphyrin ring.
- **Water Treatment:** Used in water softening to sequester metal ions like calcium and magnesium, preventing scale formation.

○ (ii) pH and pE.

▪ **pH:**

- **Definition:** pH is a measure of the acidity or alkalinity of an aqueous solution. It quantifies the concentration of hydrogen ions (H^+) or, more accurately, hydronium ions (H_3O^+) in a solution.
- **Scale:** The pH scale typically ranges from 0 to 14, where:

- pH < 7 indicates an acidic solution (higher H^+ concentration).
 - pH = 7 indicates a neutral solution.
 - pH > 7 indicates a basic (alkaline) solution (lower H^+ concentration).
- **Mathematical Relation:** $\text{pH} = -\log_{10}[\text{H}^+]$.
- **Environmental Importance:** Crucial for understanding chemical reactions in soil and water, nutrient availability for plants, the survival of aquatic organisms, and the impact of acid rain. Most biological processes operate within a narrow pH range.
- **pE:**
 - **Definition:** pE is a measure of the electron activity or the redox potential of a solution. It indicates the tendency of a solution to gain or lose electrons, thereby describing its oxidizing or reducing environment. It is analogous to pH for hydrogen ion activity.
 - **Scale:** Higher pE values indicate more oxidizing (electron-poor) conditions, while lower pE values (including negative values) indicate more reducing (electron-rich) conditions.
 - **Mathematical Relation:** $\text{pE} = -\log_{10}[\text{e}^-]$, where $[\text{e}^-]$ is the hypothetical electron activity. It is also related to the standard redox potential (E°) by $\text{pE} = \frac{F}{2.303RT} E^\circ$, where F is Faraday's constant, R is the gas constant, and T is temperature.

- **Environmental Importance:** Crucial for predicting the fate and mobility of chemical species, especially metals and organic pollutants, in natural waters and soils. It influences:
 - **Speciation of Elements:** Determines the oxidation state of elements (e.g., Fe^{2+} vs. Fe^{3+} , S^{2-} vs. SO_4^{2-}).
 - **Microbial Activity:** Influences the types of microorganisms that can thrive (aerobic vs. anaerobic).
 - **Pollutant Mobility:** Affects the solubility and adsorption of contaminants. For example, chromium can be toxic as $Cr(VI)$ under oxidizing conditions (high pE) but less mobile and toxic as $Cr(III)$ under reducing conditions (low pE).
- (iii) **Chemistry of acid rain.**
 - **Definition:** Acid rain, more accurately termed acid deposition, refers to any form of precipitation (rain, snow, fog, hail) or dry deposition (acidic gases and particles) with unusually high levels of nitric and sulfuric acids. It has a pH lower than 5.6, which is the typical pH of natural rain (slightly acidic due to dissolved CO_2).
 - **Primary Pollutants:** The main precursors to acid rain are sulfur dioxide (SO_2) and nitrogen oxides (NO_x), primarily NO and NO_2 .
 - **Sources:**
 - SO_2 : Chiefly from the combustion of fossil fuels (coal, oil) in power plants and industrial boilers, as these fuels contain sulfur impurities.

- NO_x : Produced during high-temperature combustion processes in power plants, industrial furnaces, and particularly vehicle engines.
- **Chemical Reactions in the Atmosphere:**
 - **Sulfuric Acid Formation:**
 - SO_2 is oxidized in the atmosphere to sulfur trioxide (SO_3) in the presence of sunlight, oxygen, and catalysts (like metal particles or water droplets).
 - $2SO_2(g) + O_2(g) \xrightarrow{\text{catalyst}} 2SO_3(g)$
 - $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$ (Sulfuric Acid)
 - **Nitric Acid Formation:**
 - NO_x (mainly NO and NO_2) undergoes a series of complex reactions involving ozone and hydroxyl radicals.
 - $NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$
 - $NO_2(g) + OH \cdot (g) \rightarrow HNO_3(aq)$ (Nitric Acid)
 - In the presence of water droplets, gaseous nitric acid dissolves into the rain.
- **Impacts of Acid Rain:**
 - **Environmental Damage:** Acidifies lakes and streams, harming aquatic life. Damages forests and soils by leaching essential nutrients and releasing toxic metals.

- **Infrastructure Damage:** Corrodes buildings, statues, and historical monuments (especially those made of limestone or marble).
- **Health Effects:** Fine sulfate and nitrate particles can penetrate deep into the lungs, exacerbating respiratory and cardiovascular diseases.
- **(iv) Organic and Inorganic components of Soil.**
 - Soil is a complex mixture of four major components: mineral matter (inorganic), organic matter (organic), water, and air.
 - **Inorganic Components (Mineral Matter):**
 - **Origin:** Derived from the weathering and breakdown of parent rocks and minerals.
 - **Composition:** Primarily consists of various inorganic mineral particles, which are classified by size:
 - **Sand:** Largest particles (0.05 – 2.0 mm), gritty feel. Provide good aeration and drainage.
 - **Silt:** Medium-sized particles (0.002 – 0.05 mm), floury feel. Improve water retention and nutrient holding capacity.
 - **Clay:** Smallest particles (< 0.002 mm), sticky when wet. Have a large surface area, high cation exchange capacity, and good water retention, but can impede drainage.
 - **Elements:** Major elements include silicon (*Si*), oxygen (*O*), aluminum (*Al*), iron (*Fe*), calcium (*Ca*), potassium (*K*), magnesium (*Mg*), and sodium (*Na*),

present in various mineral forms (e.g., quartz, feldspars, micas, clay minerals).

- **Function:** Provides the bulk of the soil matrix, physical support for plants, and is the primary source of many essential plant nutrients released through weathering. Influences soil texture, structure, and drainage.

▪ **Organic Components (Organic Matter):**

- **Origin:** Derived from the decomposition of plant and animal residues (leaves, roots, dead organisms, manure) and the living biomass of soil organisms (bacteria, fungi, earthworms).
- **Composition:** A diverse mixture of carbon-based compounds, ranging from fresh, identifiable plant/animal residues to highly decomposed, stable material called humus. It also includes living organisms (soil biota).
- **Key Sub-components:**
 - **Living Organisms (Biomass):** Bacteria, fungi, algae, protozoa, nematodes, insects, earthworms, etc.
 - **Dead, but Undecayed Residues:** Fresh plant litter, dead insects.
 - **Decomposing Organic Matter:** Partially decomposed plant and animal materials.
 - **Humus:** Stable, dark, amorphous, and highly colloidal organic matter that is resistant to further rapid decomposition. It is crucial for soil health.

- **Function:**

- **Nutrient Cycling:** Stores and releases essential plant nutrients (N, P, S).
- **Water Retention:** Improves soil's ability to hold water.
- **Soil Structure:** Binds soil particles into stable aggregates, improving aeration, drainage, and root penetration.
- **Cation Exchange Capacity:** Contributes significantly to the soil's ability to hold positively charged nutrients.
- **Energy Source:** Provides energy and carbon for soil microorganisms.
- **Buffering Capacity:** Helps buffer pH changes in the soil.

3. (a) **What is soil organic carbon and its composition? How is it different from soil organic matter?**

- **What is Soil Organic Carbon (SOC)?**
 - Soil Organic Carbon (SOC) refers to the carbon component within soil organic matter. It represents the total amount of carbon contained in the organic constituents of the soil, excluding inorganic carbonates.
 - It is a key indicator of soil health, fertility, and ecosystem productivity.
- **Composition of Soil Organic Carbon:**
 - SOC is not a single compound but a complex mixture of various carbon-containing organic compounds derived

from the decomposition of plant and animal residues and microbial biomass.

- Its composition is highly diverse and dynamic, including:
 - **Particulate Organic Matter (POM):** Relatively undecomposed or partially decomposed plant and animal fragments, often still recognizable.
 - **Humus (Humic Substances):** Highly stable, amorphous, dark-colored organic compounds that are resistant to further rapid decomposition. This is the largest and most stable fraction of SOC. It includes:
 - **Humic acids:** Complex macromolecules, soluble in alkaline solutions but precipitate in acidic solutions.
 - **Fulvic acids:** Smaller molecules, soluble in both alkaline and acidic solutions.
 - **Humin:** The largest and most complex fraction, insoluble in both acidic and alkaline solutions.
 - **Non-Humic Substances:** Simpler organic molecules like sugars, amino acids, proteins, lipids, carbohydrates, and organic acids. These are typically more labile (easily decomposed) and represent a smaller, more active fraction.
 - **Microbial Biomass:** Carbon contained within living and dead microorganisms (bacteria, fungi, protozoa).
- **How is it different from Soil Organic Matter (SOM)?**

- **Relationship:** Soil organic carbon (SOC) is a *component* of soil organic matter (SOM). SOM refers to the entire mass of organic material in the soil, including living organisms, fresh residues, and decomposed organic substances.
- **Measurement:**
 - **SOM:** Can be measured by loss-on-ignition (heating the soil to burn off organic matter and measuring the weight loss) or by wet combustion methods.
 - **SOC:** Measured directly as the carbon content of the organic fraction.
- **Conversion Factor:** Due to the relatively consistent carbon content in typical organic matter, SOM is often estimated from SOC measurements using a conversion factor. The most commonly used factor is 1.724 (assuming organic matter is 58 carbon).
 - So, $\$SOM = SOC \times 1.724\$$.
- **Scope:** SOM is a broader term encompassing all organic compounds. SOC specifically focuses on the carbon within that organic matter, which is often considered the most important functional component for soil health and carbon sequestration.
- **Example:** If you have a plant leaf in the soil, the entire leaf is part of the SOM. The carbon atoms within that leaf constitute the SOC. As the leaf decomposes, its overall mass (SOM) decreases, but its carbon content (SOC) becomes part of the more stable humus pool.

(b) What are redox reactions? Explain different types of redox reactions with appropriate examples.

- **What are Redox Reactions?**

- Redox reactions (reduction-oxidation reactions) are chemical reactions in which there is a change in the oxidation states of atoms by the transfer of electrons between reactants.
- **Oxidation:** Loss of electrons, resulting in an increase in oxidation state.
- **Reduction:** Gain of electrons, resulting in a decrease in oxidation state.
- These two processes always occur simultaneously; one substance is oxidized while another is reduced.
- **Explanation of Different Types of Redox Reactions with Examples:**
 - **i. Combination Reactions:**
 - **Definition:** Two or more reactants combine to form a single product. If there is a change in oxidation states of the reacting elements, it's a redox combination reaction.
 - **Explanation:** Often involves elements reacting to form a compound.
 - **Example:** Formation of water from hydrogen and oxygen.
 - $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
 - In H_2 , H has an oxidation state of 0. In H_2O , H has an oxidation state of +1. Hydrogen is oxidized (from 0 to +1).
 - In O_2 , O has an oxidation state of 0. In H_2O , O has an oxidation state of -2. Oxygen is reduced (from 0 to -2).

▪ **ii. Decomposition Reactions:**

- **Definition:** A single compound breaks down into two or more simpler substances. If the oxidation states of elements within the compound change, it's a redox decomposition reaction.
- **Explanation:** This is the reverse of a combination reaction.
- **Example:** Decomposition of mercury(II) oxide (HgO).
 - $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$
 - In HgO , Hg is +2 and O is -2.
 - In Hg , Hg is 0. Mercury is reduced (from +2 to 0).
 - In O_2 , O is 0. Oxygen is oxidized (from -2 to 0).

▪ **iii. Displacement Reactions:**

- **Definition:** An atom or ion in a compound is replaced by an atom or ion of another element. These are always redox reactions.
- **Explanation:** A more reactive element displaces a less reactive one from its compound.
- **Example:** Reaction of zinc metal with copper(II) sulfate solution.
 - $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$
 - In $Zn(s)$, Zn is 0. In $ZnSO_4$, Zn is +2. Zinc is oxidized (from 0 to +2).

- In $CuSO_4$, Cu is +2. In $Cu(s)$, Cu is 0. Copper is reduced (from +2 to 0).

▪ **iv. Disproportionation Reactions (Auto-redox Reactions):**

- **Definition:** A single element in a compound is simultaneously oxidized and reduced. The same element acts as both the oxidizing and reducing agent.
- **Explanation:** An element in an intermediate oxidation state changes into two different oxidation states (one higher, one lower).
- **Example:** Disproportionation of hydrogen peroxide (H_2O_2).
 - $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$
 - In H_2O_2 , oxygen has an oxidation state of -1 .
 - In H_2O , oxygen has an oxidation state of -2 . Oxygen is reduced (from -1 to -2).
 - In O_2 , oxygen has an oxidation state of 0. Oxygen is oxidized (from -1 to 0).

▪ **v. Combustion Reactions:**

- **Definition:** Reactions in which a substance reacts with oxygen, usually with the emission of heat and light (flame). Many combustion reactions are redox reactions.
- **Explanation:** The substance being burned is oxidized by oxygen.

- **Example:** Burning of methane (CH_4).

- $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$
- In CH_4 , carbon is -4 . In CO_2 , carbon is $+4$. Carbon is oxidized (from -4 to $+4$).
- In O_2 , oxygen is 0 . In CO_2 and H_2O , oxygen is -2 . Oxygen is reduced (from 0 to -2).

4. (a) Explain the various chemical and physical properties of water.

- **Chemical Properties of Water:**

- **Polarity:** Water is a highly polar molecule due to the bent molecular geometry and the electronegativity difference between oxygen and hydrogen. The oxygen atom has a partial negative charge, and the hydrogen atoms have partial positive charges. This polarity allows water to act as an excellent solvent.
- **Hydrogen Bonding:** The polarity of water molecules leads to the formation of strong intermolecular hydrogen bonds between the partially positive hydrogen of one molecule and the partially negative oxygen of another. This is responsible for many of water's unique properties.
- **Excellent Solvent (Universal Solvent):** Due to its polarity and ability to form hydrogen bonds, water can dissolve a wide range of ionic and polar substances (hydrophilic substances) by hydrating and surrounding their ions or molecules.
- **Amphoteric Nature:** Water can act as both an acid (donating a proton) and a base (accepting a proton). It

undergoes autoionization: $2\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq})$.

▪ **Reactivity:**

- **Hydrolysis:** Water participates in many hydrolysis reactions, breaking down compounds by reacting with them (e.g., in digestion).
 - **Hydration:** Many salts can incorporate water molecules into their crystal structure, forming hydrates.
 - **Redox Reactions:** Water can be involved in redox reactions, for example, it is oxidized to O_2 during photosynthesis and reduced to H_2 during electrolysis.
- **Neutral pH:** Pure water has a neutral pH of 7 at 25°C due to its equal concentrations of H^+ and OH^- ions.
- **Specific Heat Capacity:** Water has a remarkably high specific heat capacity ($4.184 \text{ J/g}^\circ\text{C}$). This means it can absorb or release a large amount of heat with only a small change in its own temperature. This property moderates Earth's climate.

○ **Physical Properties of Water:**

- **State at Room Temperature:** Exists as a liquid at standard room temperature and pressure, which is unusual for a molecule of its small size (due to strong hydrogen bonding).
- **High Boiling and Freezing Points:** Has unusually high boiling (100°C) and freezing (0°C) points compared to other hydrides of similar molecular weight (e.g., H_2S) due to extensive hydrogen bonding.

▪ **Density Anomaly:**

- Unlike most substances, water is densest at 4°C (about $1.0\text{g}/\text{cm}^3$) and becomes less dense as it freezes to ice ($0.92\text{g}/\text{cm}^3$).
- This anomaly means ice floats on liquid water, which is crucial for aquatic life in cold climates (insulates water below, preventing entire bodies of water from freezing solid).

▪ **High Surface Tension:** Strong cohesive forces (hydrogen bonds) between water molecules at the surface create high surface tension. This allows for phenomena like capillary action and supports small insects on water.

▪ **High Heat of Vaporization:** Requires a large amount of energy to change from liquid to gas (2260 J/g). This property is vital for evaporative cooling in plants and animals (perspiration) and for transferring heat in the atmosphere.

▪ **High Cohesion and Adhesion:**

- **Cohesion:** Water molecules stick to each other (due to hydrogen bonds).
- **Adhesion:** Water molecules stick to other polar surfaces.
- These properties enable capillary action, important for water transport in plants and in soil.

▪ **Transparency:** Transparent to visible light, allowing sunlight to penetrate aquatic environments, which is essential for aquatic photosynthesis.

(b) What is the difference between aromatic and aliphatic compounds? Give three examples of each compound with their respective molecular structure.

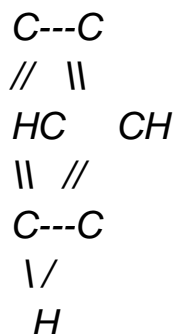
○ **Difference between Aromatic and Aliphatic Compounds:**

▪ **Aromatic Compounds:**

- **Definition:** Organic compounds that contain one or more planar, cyclic rings of atoms (typically carbon) with delocalized pi electrons, exhibiting special stability due to aromaticity (e.g., following Hückel's Rule of $4n + 2$ pi electrons). The most common aromatic system is the benzene ring.
- **Structure:** Characterized by conjugated double bonds within a ring system, leading to resonance stabilization. The bonds within the ring are often intermediate in length between single and double bonds.
- **Reactivity:** Tend to undergo substitution reactions rather than addition reactions, as addition would disrupt their stable aromatic system.
- **Smell:** Many (but not all) aromatic compounds have distinct, often strong, pleasant or pungent odors (hence "aromatic").
- **Examples:**
 - **Benzene:** A six-membered carbon ring with alternating single and double bonds (or delocalized pi electrons).

▪ **Structure:**

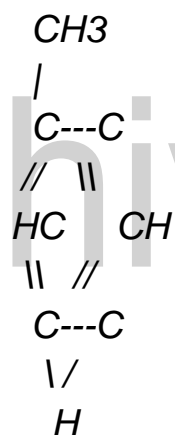




(Alternatively, a hexagon with a circle inside)

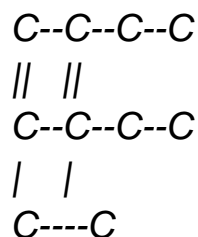
- **Toluene (Methylbenzene):** A benzene ring with one methyl group attached.

- **Structure:**



- **Naphthalene:** Two fused benzene rings.

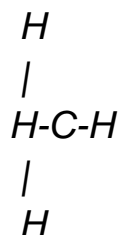
- **Structure:**



- **Aliphatic Compounds:**

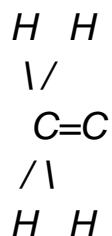
- **Definition:** Organic compounds that do not contain a benzene ring or any other aromatic ring system. Their carbon atoms are arranged in straight chains, branched chains, or non-aromatic rings.
- **Structure:** Consist of carbon and hydrogen atoms connected by single, double, or triple bonds, but without the delocalized pi electron system characteristic of aromaticity. They can be saturated (alkanes) or unsaturated (alkenes, alkynes).
- **Reactivity:** Tend to undergo addition reactions (for unsaturated compounds) or substitution reactions (for saturated compounds).
- **Smell:** Tend to have less distinctive or sometimes unpleasant smells, but many small aliphatic compounds (like methane) are odorless.
- **Examples:**
 - **Methane:** The simplest alkane, a single carbon atom bonded to four hydrogen atoms.

▪ **Structure:**



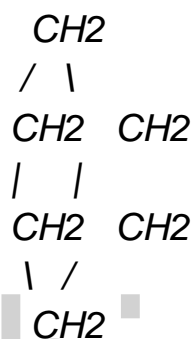
- **Ethylene (Ethene):** The simplest alkene, two carbon atoms linked by a double bond, each bonded to two hydrogen atoms.

▪ **Structure:**



- **Cyclohexane:** A six-membered non-aromatic carbon ring with only single bonds (saturated).

- **Structure:**



(A hexagon with no circle inside, representing single bonds)

5. (a) **What are phenolic compounds? How do these compounds affect soil properties?**

- **What are Phenolic Compounds?**

- Phenolic compounds are a class of organic compounds characterized by the presence of one or more hydroxyl (-OH) groups directly attached to an aromatic hydrocarbon ring (e.g., a benzene ring).
- They range from simple molecules like phenol (C_6H_5OH) to complex polymers like tannins and lignin.
- They are widely distributed in plants, acting as secondary metabolites involved in defense mechanisms, pigmentation, and structural support. They are also found

in significant quantities in soil organic matter, especially humus.

○ **How do these compounds affect soil properties?**

▪ **i. Influence on Soil Organic Matter Decomposition:**

- **Inhibition of Microbial Activity:** Many phenolic compounds, especially tannins and complex polyphenols, have antimicrobial and fungicidal properties. They can inhibit the activity of soil microorganisms involved in the decomposition of organic matter.
- **Slowing Decomposition:** By inhibiting microbial activity, phenolic compounds can slow down the decomposition rate of plant residues, leading to the accumulation of organic matter, particularly in acidic or poorly drained soils.
- **Humus Formation:** Some phenolic compounds are precursors to the formation of stable humus, contributing to the long-term sequestration of carbon in the soil.

▪ **ii. Nutrient Cycling:**

- **Nitrogen Immobilization:** Phenolics can bind with proteins and enzymes, making nitrogen less available for microbial degradation and plant uptake. This can lead to temporary nitrogen immobilization.
- **Phosphorus Availability:** They can interact with phosphorus, sometimes forming stable complexes that reduce phosphorus availability to plants, especially in acidic soils.

- **Micronutrient Chelation:** Some phenolic compounds, particularly humic and fulvic acids (which contain phenolic structures), can chelate metal micronutrients (like Fe, Mn, Cu, Zn), making them more soluble and available for plant uptake. However, at high concentrations, some simple phenolics can also complex metals and reduce their availability.
- **iii. Soil pH:**
 - Many phenolic compounds are weakly acidic due to the presence of the hydroxyl group attached to the aromatic ring.
 - **Acidification:** Their decomposition and release can contribute to the slight acidification of soil, especially in forest ecosystems where large amounts of phenolic-rich litter accumulate.
- **iv. Soil Structure and Aggregation:**
 - **Binding Agents:** Phenolic compounds, particularly the humic substances, act as binding agents, helping to aggregate soil particles. They can form complexes with clay minerals and metal ions, enhancing soil structure stability.
 - **Impact:** Improved soil structure leads to better aeration, water infiltration, and reduced erosion.
- **v. Plant Growth and Allelopathy:**
 - **Allelopathic Effects:** Some phenolic compounds released by plants into the soil (via root exudates or decomposing litter) can have allelopathic effects, inhibiting the germination or growth of other plant

species. This can influence plant community composition.

- **Plant Metabolism:** They can directly affect plant metabolism and root development.

▪ **vi. Water Quality:**

- **Leaching:** Phenolic compounds can leach from soil into groundwater and surface waters, potentially impacting water quality, taste, and odor.
- **Complexation:** In aquatic systems, they can complex with metals and organic pollutants, influencing their mobility and bioavailability.

(b) What is it called when some form of water leaves soap scum behind or calcium deposits on appliances? What is the reason for this chemical change in water and how can it be removed?

- **What is it called?**
 - This phenomenon is called **water hardness** (specifically **hard water**), and the visible residues are **soap scum** (when reacting with soap) and **limescale** or **calcium deposits** (on appliances).
- **Reason for this chemical change in water:**
 - The reason for water hardness is the presence of dissolved multivalent metallic cations, primarily **calcium ions** (Ca^{2+}) and **magnesium ions** (Mg^{2+}).
 - **Formation of Soap Scum:**
 - Traditional soaps (which are sodium or potassium salts of long-chain fatty acids) react with calcium and magnesium ions.

- For example, sodium stearate (a component of soap) reacts with calcium ions:

$$2C_{17}H_{35}COONa(aq) + Ca^{2+}(aq) \rightarrow (C_{17}H_{35}COO)_2Ca(s) + 2Na^+(aq)$$
- The product, calcium stearate (and magnesium stearate), is an insoluble precipitate, which is the "soap scum" that sticks to surfaces and is difficult to rinse off. This reaction also reduces the lathering ability of soap.

▪ **Formation of Limescale/Calcium Deposits:**

- The permanent hardness is caused by calcium sulfate ($CaSO_4$) and calcium chloride ($CaCl_2$), and magnesium sulfate ($MgSO_4$) and magnesium chloride ($MgCl_2$). These are stable salts.
- The temporary hardness is caused by the presence of dissolved calcium bicarbonate ($Ca(HCO_3)_2$) and magnesium bicarbonate ($Mg(HCO_3)_2$).
- When hard water is heated (e.g., in kettles, water heaters, pipes):
 - The bicarbonates decompose to form insoluble calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$), along with carbon dioxide.
 - $Ca(HCO_3)_2(aq) \xrightarrow{\text{heat}} CaCO_3(s) + H_2O(l) + CO_2(g)$
 - $Mg(HCO_3)_2(aq) \xrightarrow{\text{heat}} Mg(OH)_2(s) + 2CO_2(g)$

- These insoluble precipitates form the hard, white, scaly deposits known as limescale, which can accumulate on heating elements and pipe interiors, reducing efficiency and potentially causing damage.
- **How can it be removed?**
 - **For Temporary Hardness (removable by boiling):**
 - **Boiling:** Heating water causes bicarbonates to decompose into insoluble carbonates, which precipitate out. This only works for temporary hardness.
 - **For Permanent Hardness (requires other methods):**
 - **i. Ion Exchange (Water Softeners):**
 - **Method:** This is the most common method for household water softening. Hard water passes through a tank containing resin beads coated with sodium ions.
 - **Chemical Change:** As water flows through, the calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in the water are exchanged for the sodium ions (Na^+) on the resin. The soft water (now containing sodium ions) leaves the system.
 - **Regeneration:** When the resin is saturated with hard ions, it is "regenerated" by flushing it with a concentrated brine (salt) solution, which replaces the hard ions with sodium ions again.
 - $Ca^{2+}(aq) + 2NaR(s) \rightarrow CaR_2(s) + 2Na^+(aq)$ (R represents the resin)

- **ii. Chemical Softening (Lime-Soda Process):**

- **Method:** Adding chemicals like lime (calcium hydroxide, $Ca(OH)_2$) and soda ash (sodium carbonate, Na_2CO_3) to precipitate out the calcium and magnesium ions.
- **Chemical Change:**
 - $Ca^{2+}(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2Na^+(aq)$
 - $Mg^{2+}(aq) + Ca(OH)_2(aq) \rightarrow Mg(OH)_2(s) + Ca^{2+}(aq)$
 - This method is usually used in industrial or municipal water treatment plants.

- **iii. Reverse Osmosis (RO):**

- **Method:** Water is forced under pressure through a semi-permeable membrane that has tiny pores.
- **Chemical Change:** The membrane allows water molecules to pass through but blocks larger dissolved ions, including calcium and magnesium, thus effectively removing hardness and many other impurities.

- **iv. Distillation:**

- **Method:** Boiling the water and collecting the condensed steam.
- **Chemical Change:** This leaves behind all non-volatile impurities, including hardness-causing ions. It's effective but energy-

intensive and not practical for large-scale home use.

- **v. Chelating Agents (e.g., EDTA in detergents):**
 - **Method:** Many detergents contain chelating agents (like phosphates or EDTA) that bind to calcium and magnesium ions, preventing them from reacting with soap and forming scum.
 - **Chemical Change:** These agents sequester the ions in soluble complexes rather than removing them from the water.

6. Recently, many studies suggested that the Indo-Gangetic plain has some of the most polluted air quality which is many times above the WHO guidelines. Using appropriate chemical reactions, explain the changes that occur in the atmospheric chemistry with the amplification of air pollutants in the region. Also, explain ways to combat this environmental issue by citing appropriate examples.

The Indo-Gangetic Plain (IGP) indeed faces severe air pollution, driven by a combination of high population density, industrialization, vehicular emissions, agricultural burning, and geographical factors (like winter inversions). The amplification of air pollutants leads to significant changes in atmospheric chemistry, with detrimental effects.

Changes in Atmospheric Chemistry with Amplification of Air Pollutants:

a. Increased Particulate Matter ($PM_{2.5}$, PM_{10}):

- **Sources:** Direct emissions from combustion (vehicles, industries, biomass burning), dust, and secondary formation from gaseous precursors.

- **Chemical Change:** Gaseous pollutants like SO_2 , NO_x , and volatile organic compounds (VOCs) undergo atmospheric oxidation and reactions to form fine secondary particulate matter (sulfates, nitrates, organic aerosols).
 - $SO_2(g) + OH \cdot(g) \rightarrow HOSO_2 \cdot(g) \xrightarrow{O_2, H_2O} H_2SO_4(aq) \rightarrow \text{Sulfate aerosols}$
 - $NO_2(g) + OH \cdot(g) \rightarrow HNO_3(aq) \rightarrow \text{Nitrate aerosols}$
 - **Impact:** PM causes respiratory and cardiovascular diseases, reduces visibility (haze), and affects radiative forcing.

b. **Formation of Ground-Level Ozone (O_3) and Photochemical Smog:**

- **Sources:** Not directly emitted but formed from precursors: Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOCs) in the presence of sunlight.
- **Chemical Change (Simplified Cycle):**
 - $NO_2(g) \xrightarrow{\text{sunlight}} NO(g) + O(g)$
 - $O(g) + O_2(g) \rightarrow O_3(g)$ (Ground-level Ozone)
 - This ozone can then react with NO: $NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$
 - In urban areas with high VOCs, the VOCs react with NO, preventing NO from destroying ozone. Instead, VOCs are oxidized, generating more NO_2 , which continues the cycle, leading to ozone accumulation.

- **Impact:** Ozone is a potent respiratory irritant, damages crops and ecosystems, and is a strong greenhouse gas. Photochemical smog (a brownish haze) reduces visibility and contains a complex mixture of harmful oxidants.

c. **Acidification of Precipitation (Acid Rain):**

- **Sources:** High emissions of Sulfur Dioxide (SO_2) from industrial burning of fossil fuels (especially coal) and Nitrogen Oxides (NO_x) from combustion processes.
- **Chemical Change:** These gases react with water vapor and oxidants in the atmosphere to form sulfuric acid and nitric acid.
 - $2SO_2(g) + O_2(g) \xrightarrow{\text{catalyst}} 2SO_3(g)$
 - $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$
(Sulfuric Acid)
 - $NO_x(g) + O_2(g) + H_2O(l) \xrightarrow{\text{sunlight}} HNO_3(aq)$ (Nitric Acid)
- **Impact:** Acidifies soil and water bodies, harms aquatic life, damages forests, and corrodes infrastructure and cultural heritage sites.

d. **Increased Greenhouse Gas Concentrations (beyond CO_2):**

- **Sources:** Beyond CO_2 , the IGP region sees elevated levels of methane (CH_4) from agriculture (rice paddies, livestock), and nitrous oxide (N_2O) from fertilizer use.
- **Chemical Change:** While their direct atmospheric chemistry is relatively stable, their presence amplifies the greenhouse effect. Methane has a much higher global warming potential than CO_2 over a shorter timescale.

- **Impact:** Contributes to regional and global warming, exacerbating climate change impacts.

e. Formation of Toxic Organic Compounds:

- **Sources:** Incomplete combustion of fossil fuels and biomass burning releases a cocktail of unburnt hydrocarbons and VOCs.
- **Chemical Change:** These VOCs can react with atmospheric oxidants (like hydroxyl radicals, $\text{OH} \cdot$) and NO_x to form secondary organic aerosols (SOAs) and other toxic compounds, including polycyclic aromatic hydrocarbons (PAHs) and aldehydes.
- **Impact:** Many of these are carcinogenic or otherwise harmful to human health.

Ways to Combat this Environmental Issue (with examples):

f. Transition to Cleaner Energy Sources:

- **Explanation:** Shifting away from fossil fuels (coal, oil) to renewable energy sources significantly reduces emissions of SO_2 , NO_x , PM, and CO_2 .
- **Example:** Large-scale deployment of solar farms (e.g., Bhadla Solar Park in Rajasthan), wind energy projects, and promotion of rooftop solar panels for residential and commercial use. Investing in cleaner industrial processes.

g. Improve Vehicular Emission Standards and Public Transport:

- **Explanation:** Implementing stricter emission norms for vehicles, promoting electric vehicles (EVs), and investing in efficient public transportation can drastically cut urban air pollution.

- **Example:** India's transition to Bharat Stage VI (BS-VI) emission standards for vehicles, promoting electric buses in major cities, and expanding metro rail networks (e.g., Delhi Metro, Lucknow Metro) to reduce private vehicle dependency.

h. Sustainable Agricultural Practices:

- **Explanation:** Addressing agricultural stubble burning (a major source of winter pollution in the IGP) and optimizing fertilizer use to reduce N_2O and ammonia (NH_3) emissions.
- **Example:** Promoting in-situ management of crop residue using happy seeder machines (which sow wheat without burning stubble), developing alternative uses for stubble (e.g., biomass pellets, animal fodder), and encouraging precision agriculture to reduce excessive fertilizer application.

i. Industrial Emission Control and Technological Upgrades:

- **Explanation:** Mandating and enforcing the use of pollution control devices (e.g., scrubbers for SO_2 , electrostatic precipitators for PM) in industries and power plants. Encouraging adoption of cleaner production technologies.
- **Example:** Implementation of Flue Gas Desulfurization (FGD) units in thermal power plants to capture SO_2 emissions. Phasing out older, more polluting industrial units.

j. Waste Management and Biomass Burning Control:

- **Explanation:** Proper collection, segregation, and processing of municipal solid waste to prevent open

burning, which is a significant source of PM and toxic gases.

- **Example:** Promoting waste-to-energy plants, composting, and discouraging open burning of waste in urban and rural areas.

k. **Urban Planning and Green Infrastructure:**

- **Explanation:** Designing cities to reduce vehicle miles traveled, promote walking/cycling, and incorporating green spaces to absorb pollutants and improve air quality.
- **Example:** Developing green belts, increasing tree cover in urban areas (trees can absorb some pollutants and PM), and planning for mixed-use developments to reduce commuting.

l. **Public Awareness and Behavioral Change:**

- **Explanation:** Educating the public about the health impacts of air pollution and encouraging individual actions like using public transport, conserving energy, and reducing waste.
- **Example:** Government campaigns like "Grameen Paryavaran Chetna Abhiyan" to raise awareness in rural areas and public health advisories during high pollution episodes.

By implementing a multi-faceted approach addressing both primary emissions and the underlying socio-economic drivers, the atmospheric chemistry of the Indo-Gangetic Plain can be improved, leading to better air quality and public health.