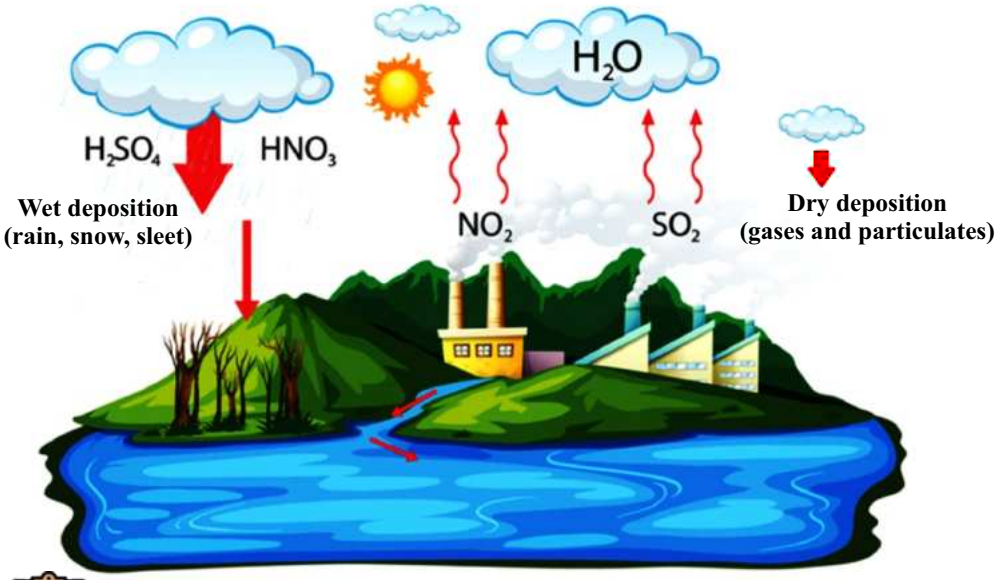
CHAPTER 12 ENVIRONMENTAL CHEMISTRY

Teaching Periods	09	Assessment	01	Weightage %	08



Students will be able to:

- ✓ Recognize various chemical reactions occurring in the atmosphere. (Understanding)
- ✓ Recognize that the release of COx, SOx, NOx, VOCs are associated with the combustion of hydrocarbon based fuels. (Applying)
- ✓ Outline problems associated with release of pollutants including acid rain. (Understanding)
- ✓ Describe causes and impacts of smog. (Analyzing)
- ✓ Explain greenhouse effect and global warming as resulting in climate change. (Analyzing)
- ✓ Explain the buildup and the adverse effects of ozone in the troposphere. (Applying)
- ✓ Describe the role of CFCs in destroying ozone in the stratosphere. (Applying)
- ✓ Describe the role of ozone in the stratosphere in reducing the intensity of harmful UV radiation reaching the earth. (Understanding)
- ✓ List possible alternatives of CFCs. (Applying)
- ✓ Recognize and describe various water pollutants. (Applying)
- ✓ Explain the various parameters of drinking water analysis and compare with WHO standard limits. (Applying)
- ✓ List some major products of petrochemicals industry with their uses. (Applying)

INTRODUCTION

Environmental chemistry is a special area of chemistry that look at how chemicals interact in the environment and effect living things. **"It deals with the study of chemical processes happening in Earth's environment and their direct or indirect impact on organisms that live on Earth"**.

"The presence of undesirable substances in the environment that harm the natural balance of eco systems is known as environmental pollution". There are several types of pollution that can negatively impact the environment and human health such as air pollution, water pollution, soil pollution, noise pollution, radioactive pollution etc. Earth's environment consists of four interconnected parts that work together to sustain life. These parts include;

- **Lithosphere** which comprises Earth crust and soil covering with the rocks.
- **Hydrosphere** which consists of all surface and underground water.
- **Biosphere** which includes the entire living being on the Earth.
- **Atmosphere** which is extended to 500 km above the Earth's surface and consists of gases.

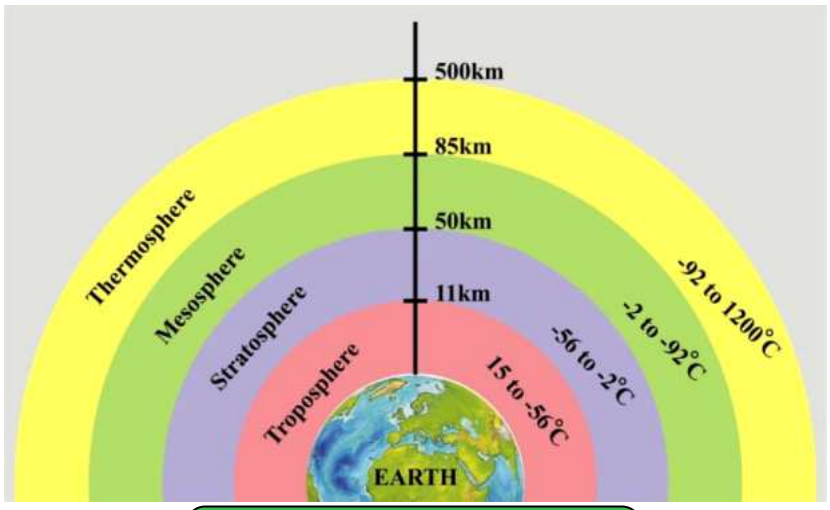


Fig 12.1: Four regions of earth atmosphere

The Earth's atmosphere is further divided into four major regions based on variation in the temperature and compositions. These regions are commonly known as atmospheric layers.

Troposphere: It is the lowest layer of atmosphere extending from Earth's surface up to an altitude of 11km.
Stratosphere: It starting from the top of troposphere and extending up to 50km above the Earth's surface.
Mesosphere: It lies above stratosphere stretching from 50km to 85km above the Earth's surface.
Thermosphere: It is the upper most layer of the Earth's atmosphere extending from 85km to 500km.

12.1 CHEMISTRY OF THE TROPOSPHERE

Troposphere is the lowest layer of Earth's atmosphere, where we experience our daily weather conditions such as rain, snow, winds, storms, thunders, clouds. The temperature in this region decreases constantly with increasing altitude from the ground of Earth's surface approximately 15°C to -56°C. The air pressure at sea level is nearly 760 torr but it decreases with increasing the altitude. This region plays a vital role in supporting life on Earth as it holds as significant portion of oxygen, carbon dioxide and water vapours which are essential for the sustenance of living organisms.

DO YOU KNOW?

Thermosphere is the highest temperature region of atmosphere due to the absorption of intense solar radiation. They natural light display known as aurora is occurred in this region.

12.1.1 Reactions of CO_x, NO_x, VOC_s, SO_x and O_3 with the atmosphere

Gases like nitrogen (N_2) and oxygen (O_2) form a protective layer in the Earth's atmosphere. However, certain toxic substances, including nitrogen oxides (NO_x) sulphur oxides (SO_x), volatile organic compounds (VOCs) and ozone (O_3) can cause atmospheric pollution.

Chemistry of oxides of carbon (CO_x)

The oxides of carbon in troposphere are carbon monoxide (CO) and carbon dioxide (CO_2), collectively written as CO_x.

Carbon monoxide is very toxic gas, since it has great affinity for hemoglobin. It is released by the partial combustion of fuel in automobile,

petroleum refining and forest fire etc. Carbon monoxide in troposphere is broken down by U.V radiation into free carbon particles which are responsible for the smog formation.

$$CO_{(g)} + h\upsilon \longrightarrow C_{(s)} + \frac{1}{2}O_{2(g)}$$

Carbon dioxide is added to atmosphere due to the combustion of fossil fuels such as coal, wood, petroleum. It is also released during the respiration of animals. The increase level of carbon dioxide in atmosphere causes suffocation and respiratory disorders.

Chemistry of Oxides of Nitrogen (NOx)

There are two main oxides of nitrogen which cause pollution of air. These are nitric oxide (NO) and nitrogen dioxide (NO_2) and are collectively written as NOx. These oxides produce from the combustion of fuel such as coal, petrol and natural gases at high temperature.

$$N_{2(g)} + O_{2(g)} \xrightarrow{\text{U.V light}} 2NO_{(g)}$$

$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$$

These gases are also formed by photolytic reaction in atmosphere.

$$NO_{2(g)} + h\upsilon \longrightarrow NO_{(g)} + \frac{1}{2}O_{2(g)}$$

$$O + O_2 \longrightarrow O_3$$

The high concentration of NO and NO_2 gases in air is harmful because they form acid rain and ozone in the atmosphere.

Chemistry of Oxides of Sulphur (SO_X)

There are two oxides of sulphur found in air named as sulphurdioxide (SO_2) and sulphur trioxide (SO_3), these are together abbreviated as SO_x. The pollution of SO_x is equally due to volcanic eruption and the burning of sulphur containing coal in thermal power plants.

In atmosphere SO_3 gas can be produced by photochemical oxidation of SO_2 under the influence of sun light.

$$2SO_{2(g)} + O_{2(g)} \xrightarrow{\text{U.V light}} 2SO_{3(g)}$$

The presence of these gases in atmosphere causes cardial and respiratory diseases and also effect negatively on crops production.

Chemistry of Volatile Organic Compounds (VOCs)

Volatile organic solvents are commonly used in various chemical industries such as paints, varnishes, cosmetics, aerosols, air freshener and gasoline. During the chemical processes taking place in the factories, these chemical evaporates into the Earth's atmosphere and leading to the pollution. **"All those solvents which evaporate into atmosphere and contribute the atmospheric pollution are known as volatile organic compound (VOCs)"**.

DO YOU KNOW?

The industrial areas are experiencing severe pollution due to the presence of diverse industrial waste. These wastes are either released into the atmosphere or discharged into the stream, ultimately reaching the sea and causing pollution that impacts negatively on aquatic life.

Although the presence of volatile organic compounds (VOCs) in the Earth's atmosphere poses a threat to us, their exposure to ultra violet light lead to their decomposition and the formation of ozone which is even more hazardous for health. Examples of VOCs include formaldehyde, benzene, and toluene.

Chemistry of Ozone (O_3)

Ozone is an allotropic form of oxygen. It is present in a very low concentration in troposphere. Its presence is hazardous to both human health and the environment. Its side effects include respiratory issues, cardiac issues and irrigation of plants and crops.

12.1.2 Automobile Pollutants and the Catalytic Converter

The burning of gasoline in a car engine results in the formation of carbon monoxide (CO), nitric oxide (NO) and various unburnt volatile hydrocarbons. These substances, when released into the air, contribute to atmospheric pollution and have a direct impact on life. To solve this issue, modern car engines are equipped with catalytic converter **"The purpose of catalytic converter is to transform**

Fig 12.2:
Catalytic converter of automobile engine

the harmful chemicals produced during internal combustion of engine into less harmful or non harmful substances such as carbon dioxide (CO_2), nitrogen (N_2), oxygen (O_2) and water (H_2O)". Catalytic converter contain a mixture metals such as platinum and palladium which serves as catalyst.

Self Assessment

(i) Can a vehicle run without catalytic converter?
(ii) How does catalytic converter contribute to reducing air pollution.

12.1.3 Industrial Smog

Smog is a type of air pollution. This term is the combination of smoke and fog.

In the industrial zones of a country, numerous industries are operational, manufacturing various valuable commercial products. However, during the chemical processes involved, a significant number of harmful by-products are emitted into the atmosphere. Some industries release sulphurdioxide (SO_2) when burning coal and oil while other introduce harmful solid particles like metal oxides, salt particles and even soil into the air (Fig.12.3). The mixing of these harmful substances contributes to the formation of smog **"Smog is a mixture of SO_2, aerosols and volatile organic compounds"**. It forms a brown-yellow layer usually in industrial areas. Smog has many harmful side effects on human health, plant growth and overall a major contributor of environmental pollution.

Fig 12.3 Atmospheric pollution due to industrial smog

12.1.4 Global warming and Climate Change

"Global warming refers to the gradual rise in Earth's average surface temperature". The average temperature of earth is approximately 15°C but due to long term climate change resulting from global warming is causing shifts in average temperature worldwide atmosphere.

"The temperature of our earth is regulated by certain gases present in the atmosphere such as CH_4, CO_2, N_2O and H_2O known as green house gases". The change in concentration of these gases can lead to alterations in the Earth's climate.

To prevent global warming, we need to reduce greenhouse gas emissions by alternating to renewable energy sources, promoting energy efficiency, and implementing sustainable practices in sectors like transportation and agriculture.

Green House Effect

It is an essential natural process that helps in regulating the Earth's temperature enabling the existence of life on our planet (Fig.12.4).

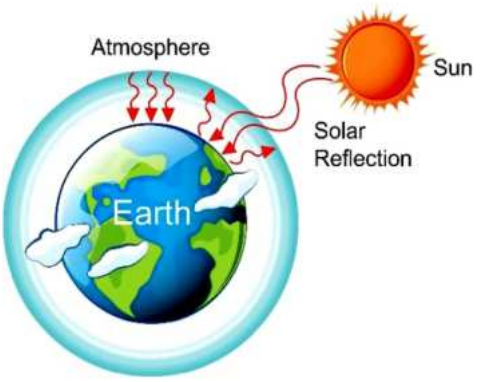


Fig 12.4 Green house effect

Sun release energy in the form of sunlight, which then reaches the earth atmosphere and a portion of it (UV and visible radiation) is absorbed by the earth which makes the earth warm. The warm surface of earth is then emitting radiation of IR frequency.

The green house gases in the atmosphere(CH_4, H_2O, CO_2 etc) absorbs some of IR radiations emitted by the Earth's surface. The absorption of heat by green house gases prevents the escaping of heat into the space. The absorbed heat energy by green house gases is reemitted toward the earth surface and warms it.

Global warming causes a widespread rise in temperature all around the world. This has a significant impact on climate change leading to various consequences such as the melting of glaciers, rising sea levels, acid rain, irregular crop pattern and even changes in human life style.

Self Assessment

- Why climate change occurs?
- What measures can be taken to mitigate climate change?

12.1.5 Acid Rain

The term acid rain was first introduced by an English chemist Robert Angus in 1872. **"Acid rain refers to rainfall that has acidic components such as nitric acid, sulphuric acid and carbonic acid"**.

The pH of normal rainfall generally ranges between 6 to 6.5 but the pH of acid rain is below 5 depending upon the concentration of acidic components present in it.

Pollutants like oxides of carbon, nitrogen and sulphur are present in the atmosphere. These oxides may undergo chemical reaction with atmospheric water to produced sulphuric acid (H_2SO_4), nitric acid (HNO_3) and carbonic acid (H_2CO_3). These acidic components mixed with rainwater and fall to the earth as acid rain (Fig.12.5).

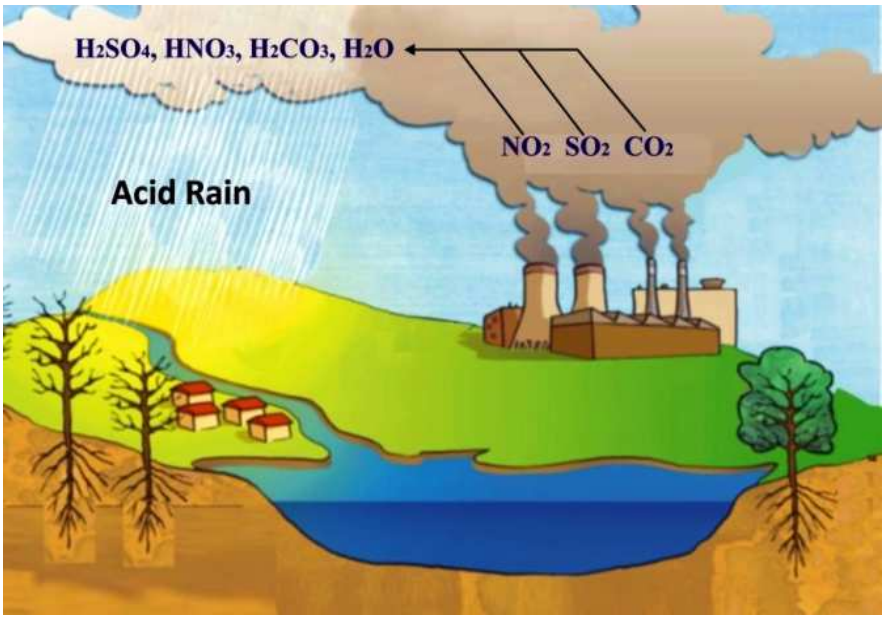


Fig 12.5: Global warming and climate change

Acid rain has several adverse effects on the environment and human life style for example.

(i) Acid rain increases the acidity of rivers, which affect negatively on aquatic animals and plants causing a disturbance of eco system.

(ii) Acid rain reduces soil fertility due to lowering in soil pH from their normal range and ultimately effect on crops production.

(iii) Acid rain causes corrosion of buildings, bridges and other concrete and metal made things.

(iv) Acid rain makes the underground water toxic and undrinkable.

Self Assessment

What is acid rain? Explain the primary causes of acid rain and its environmental impacts.

24.2 CHEMISTRY OF STRATOSPHERE

The region from 11km to 50km above the Earth's surface is referred as stratosphere. This region is distinguished by the remarkable presence of ozone (O_3) layer. This layer plays a vital role in blocking and absorbing maximum portion of sun harmful radiations (Fig.12.6). The life on the Earth's would not be possible without the protection of this layer.

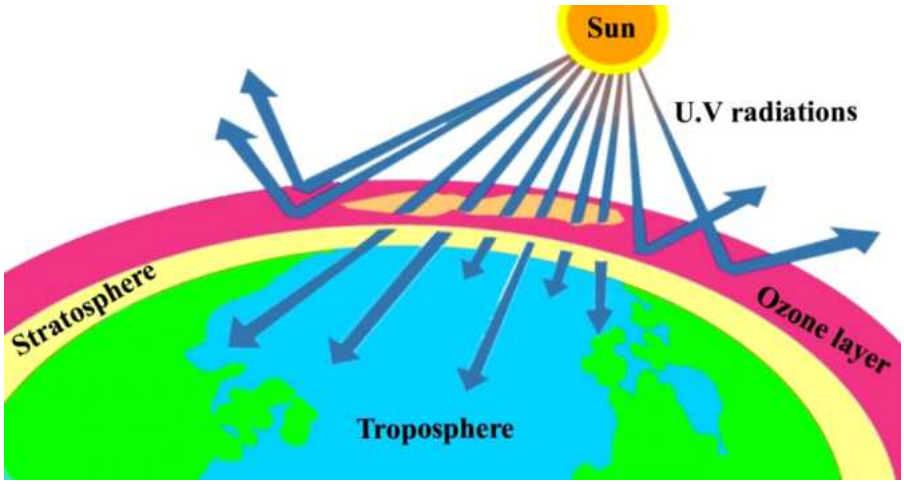


Fig 12.6: Protection of earth from hazardous U.V radiations by Ozone layer

12.2.1 Production and destruction of ozone

Ozone is produced in stratosphere region due to photochemical reaction of sun rays and oxygen gas. Ultra-violet radiations of sunlight breaks oxygen molecule (O_2) into free radicals. The oxygen free radicals are then combine with another oxygen molecule to produce ozone.

$$O_2 \xrightarrow{\text{U.V radiations}} O\bullet + \bullet O$$

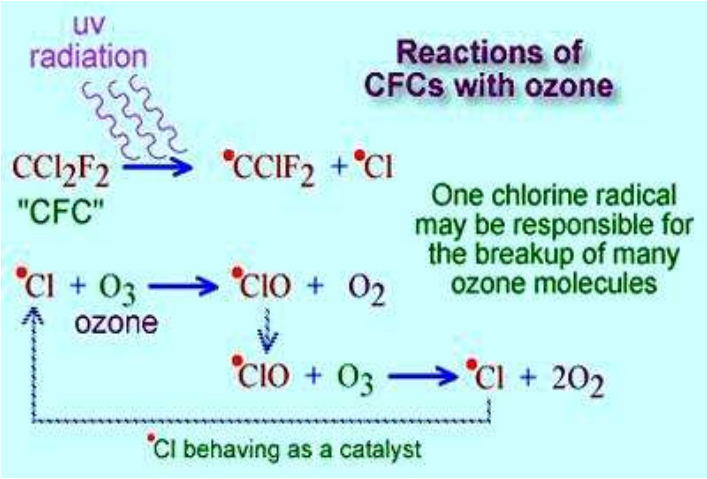
$$O\bullet + O_2 \longrightarrow O_3$$

Ozone in stratosphere also destroyed by solar energy but the two phenomena are in equilibrium and hence the thickness of ozone layer remain undisturbed.

Human activities can contribute the depletion of ozone layer through the emission of certain chemicals known as ozone-depletion substances (ODS). The most considerable human activity that have been responsible for ozone depletion is the release of gases from cooling devices such as refrigerator and air conditioners.

Chlorofluoro Carbon (CFCs)

Chlorofluoro carbons is a highly stable gas used as coolant in refrigeration and also as repellent in aerosol spray. When (CFCs) reaches into stratosphere region, it breakdown into free chlorine and fluorine atoms which then react with ozone in U.V light and decompose it into oxygen.



DO YOU KNOW?

An ozone meter is a device used to measure and monitor the concentration of ozone (O_3) in the air, providing valuable data for assessing air quality and potential health risks associated with high ozone levels.

To address the problem of (CFCs) causing ozone depletion, scientists have been working on developing alternatives to (CFCs) in order to prevent further damage to the ozone layer. The best alternative is hydrofluoro carbons (HFCs) which do not have chlorine and do not contribute to ozone depletion.

Self Assessment

What is the process of ozone formation in the stratosphere? How does the ozone layer provide protection for life?

12.3 WATER POLLUTION AND WATER ANALYSIS

About 75% of the Earth's is covered with water. Population explosion, industrialization, urbanization and many other human activities made the water polluted. **"Any undesirable change in the quality of water which affect the life adversely is known as water pollution"**.

12.3.1 Types of Water Pollution

The addition of pollutant substances alter the physical, chemical or biological properties of water and makes it unfit for the health of human. The substance which causes water pollution is classified into following three groups.

12.3.1.1 Suspended Solids and Sediments

"Small solid particles such as dust, coal microscopic organisms etc which remain suspended in the water are called colloids and the particles such as sand, clay which settle down to the bottom are called sediments". These are the common pollutants of rivers, lakes and streams which produce turbidity in water and reduce the amount of sun light available to aquatic animals .

Fig 12.7: Pollution of sea due to municipal wastes

12.3.1.2 Dissolved Solids

Various organic and inorganic compound found in water. Inorganic solids consists of minerals, salts, metal cations like calcium, magnesium, sodium, potassium and anions such as chlorides, carbonates, bicarbonates, sulphates.

The organic solids originate from organic sources such as decomposition of animals, plants and microorganisms. Both inorganic and organic solids have very small particle size and hence soluble in water. They comes from industrial water and sewage. When they fall into the river or oceans, effect negatively on aquatic life.

12.3.1.3 Waste Water Analysis

Samples of waste water are collected from different areas and analysis them by involving through a series of tests.

(i) Physical test: These include estimation of odour, colour and taste.

(ii) Chemical test: These involve the checking of pH, presence of biocides and toxic chemical.

(iii) Microbiological test: These tests involve checking for the presence of harmful bacteria and other microorganisms.

(iv) Organic test: These tests are performed for the presence of pesticides and volatile organic solvents such as petrol, benzene, toluene etc.

Parameter of drinking water analysis

To ensure the safety and quanlity of drinking water, a variety of parameters are examined. Some essential parameters generally assessed during drinking water analysis along with their corresponding standard set by WHO are given below:

(i) pH: It is an indicator of acidity or alkalinity of water. The WHO recommended pH range for drinking water is 6.5 to 8.5.

(ii) Turbidity: It refers the cloudiness of water due to suspended particles. The WHO recommendation for turbidity is less than 5 turbidity unit.

(iii) Total dissolved solids (TDS): All inorganic and organic solid particles suspended into the water are collectively known as total dissolved solids (TDS). The WHO guideline for TDS is below 600 mg/l.

(iv) Chlorine residue: Chlorine residue means the chlorine remains present in the water after chlorination process. WHO, recommended less than 0.2 mg/l in the drinking water.

(v) For freshwater bodies used for drinking water purposes, the WHO recommends BOD levels to be below 5 mg/L and COD levels to be below 10 mg/L.

12.4 GREEN CHEMISTRY

"The design and development of processes that minimize or eliminate the use of hazardous chemicals is known as green chemistry". Green chemistry aims to create safer chemicals and processes to make the environment friendly. There are twelve rules of green chemistry.

(i) **Prevent waste**: Design chemical synthesis to avoid waste. There should be no waste material left for treatment or clean up.

(ii) **Maximize atom economy**: Design syntheses to get the maximum product out of the starting materials. Avoid un-reacted material.

(iii) **Design less hazardous chemical syntheses**: Design synthetics techniques for the use and production of substances that are of little or no toxicity to humans and the environment.

(iv) **Design safer chemicals and products**: Develop chemical products that are completely effective, yet have little or no toxicity.

(v) **Use safer solvents and reaction conditions**: Avoid the use of solvents and other supporting chemicals. If any is unavoidable, use the safer ones.

(vi) **Increase energy efficiency**: Design chemical reactions that can be carried out at room temperature and pressure.

(vii) **Use renewable feedstock**: Use renewable raw materials in chemical industry rather depletable. The source of renewable raw materials is often agricultural products or by-product of industrial processes**.** Sources of depleting resources are often fossil fuels **(**oil, natural gas, or coal).

(viii) **Use catalysts, not stoichiometric reagents**: Use catalytic reactions to minimize waste. The catalyst is effective in small amount and can carry out same reaction multiple times. They are preferred over stoichiometric reagents used in larger quantity and are carried out only once.

(ix) **Design chemicals and products to degrade after use**: Design chemical products which decompose into harmless substances and do not accumulate in the environment.

(x) **Analyze in real time to prevent pollution**: Include in-process, real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.

(xi) **Minimize the potential for accidents**: Design safer techniques for chemicals and their physical forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

SOCIETY, TECHNOLOGY AND SCIENCE

Three ways of water purification

(i) Distillation: It involves the heating of water to its boiling point to vapourized it and then condensing the vapours back into liquid form which left the impurities behind.

(ii) Filtration: Filter paper or other filter devices consists of small pores. They allows the passage of water while capturing larger particles.

(iii) Reverse Osmosis: In this method water is subjected to high pressure and forced through a semi permeable membrane from the impure side to pure side. Tiny pores of semi permeable membrane prevent impurities and allow to pass water molecules thereby producing purified water.

SUMMARY

- Environmental chemistry deals with the study of chemical processes happening in Earth's environment and their direct or indirect impact on organisms that live on Earth.
- Troposphere is the lowest layer of atmosphere extending from Earth's surface up to an altitude of 11km.
- Stratosphere starting from the top of troposphere and extending up to 50km above the Earth's surface.
- Mesosphere lies above stratosphere stretching from 50kg to 85km above the Earth's surface.
- Thermosphere is the upper most layer of the Earth's atmosphere extending from 85km to 500km.
- Certain toxic substances, including nitrogen oxides (NOx) sulphur oxides (SOx), volatile organic compounds (VOCs) and ozone (O_3) can cause atmospheric pollution.

- All those solvents which evaporates into atmosphere and contribute the atmospheric pollution are known as volatile organic compound (VOCs).
- Catalytic converter is a device use in automobile for the conversion of harmful chemicals produced during internal combustion of engine into less harmful or non harmful substances.
- Catalytic converter contains a mixture metals such as platinum and palladium which serves as catalyst.
- Smog is a mixture of SO_2, aerosols and volatile organic compounds.
- Global warming refers to the gradual rise in Earth's average surface temperature.
- Green house effect is an essential natural process that helps regulating the Earth's temperature enabling the existence of life on our planet.
- Acid rain refers to rainfall that has acidic components such as nitric acid, sulphuric acid and carbonic acid.
- Ozone is produced in stratosphere region due to photochemical reaction of U.V rays of sunlight and oxygen gas.
- Human activities can contribute the depletion of ozone layer through the emission of certain chemicals known as ozone-depletion substances (ODS).
- The chemical which is the most effective for ozone depletion is cholorofluorocarbons (CFCs) which are released from cooling devices.
- Any undesirable change in the quality of water which affect the life adversely is known as water pollution.
- Waste water analysis can be done by a series of methods such as physical methods, chemical methods, microbiological methods and organic methods.
- The design and development of processes that minimize or eliminate the use of hazardous chemicals is known as green chemistry.

EXERCISE

Multiple Choice Questions

(i) The greenhouse gas is:
(a) Oxygen (O_2) (b) Nitrogen (N_2)
(c) Argon (Ar) (d) Carbon dioxide (CO_2)

(ii) The pH of acid rain is:
(a) Between 7 to 8 (b) Between 6 to 7
(c) Below 5 (d) Above 8

(iii) Ozone depletion in upper atmosphere is mainly caused by:
(a) Sulphur dioxide (SO_2) (b) Nitrogen oxides (NO_x)
(c) Carbon monoxide (CO) (d) Chlorofluorocarbons (CFCs)

(iv) The region of sphere which extend from 11km to 50km from our Earth's is known as:
(a) Troposphere (b) Stratosphere
(c) Mesosphere (d) Thermosphere

(v) The increase in global average temperatures is primarily attributed to:
(a) Solar radiations (b) Oxides of sulphur (SOx)
(c) Green house gases emission (d) Natural climate variations

(vi) The primary goal of green chemistry is:
(a) Maximizing industrial production
(b) Minimizing waste generation
(c) Reducing energy consumption
(d) Developing environmentally friendly chemicals

(vii) Smog is word used for the combination of:
(a) Water vapours and frog (b) Smoke and fog
(c) Sediments and colloids (d) Oxides of nitrogen and sulphur

(viii) The catalyst used in automobile catalytic converter is a mixture of:
(a) Pt and Pd (b) Ni and Fe
(c) Cu and Cr (d) Pb and Hg

(ix) Ozone layer is present in which of the following region of atmosphere:

(a) Troposphere (b) Stratosphere

(c) Mesosphere (d) Thermosphere

(x) The major source of water pollution is:

(a) Organic farming (b) Global warming

(c) Industrial activities (d) Renewable energy sources

Short Questions

1. Write the name of four segments of atmosphere and mention in which segment we live.
2. Explain the causes of depletion of ozone layer.
3. What is industrial smog and how is it formed?
4. What are the main gases responsible for green house effect?
5. Explain four fundamental methods for the testing of waste water.

Descriptive Questions

1. What is the effect of acid rain on human health and what measures can be taken to prevent acid rain?
2. What is the main cause of Global warming? How does it effect on weather pattern?
3. Describe the chemistry involves due to the presence of oxides of nitrogen and sulphur in the troposphere.
4. What is Green house effect? How does human activities contributes to the enhancement of the green house effect?
5. What are ozone depletion substances (ODS)? What human activities have contributed to ozone depletion in the stratosphere?
6. What is a catalytic converter? What are the main pollution targeted by catalytic converter?