

# Environmental Chemistry

## Student Learning Outcomes

After studying this chapter, students will be able to:

- State that composition of clean, dry air is approximately 78% nitrogen, N, 21% oxygen, O<sub>2</sub>, and the remainder as a mixture of noble gases and carbon dioxide, CO<sub>2</sub>
- State the major sources of air pollutants (Some examples include:
  - a. carbon dioxide from the complete combustion of carbon-containing fuels
  - b. carbon monoxide and particulates from the incomplete combustion of carbon-containing fuels
  - c. methane from the decomposition of vegetation and waste gases from digestion in animals
  - d. oxides of nitrogen from car engines
  - e. sulfur dioxide from the combustion of fossil fuels which contain sulfur compounds
  - f. ground level ozone from reactions of oxides of nitrogen, from car engines, and volatile organic compounds, in presence of light
- State the adverse effects of air pollutants (Some examples include:
  - a. carbon dioxide: higher levels of carbon dioxide leading to increased global warming, which leads to climate change
  - b. carbon monoxide: toxic gas
  - c. particulates: increased risk of respiratory problems and cancer
  - d. methane: higher levels of methane leading to increased global warming, which leads to climate change
  - e. oxides of nitrogen: acid rain, photochemical smog and respiratory problems
  - f. sulfur dioxide: acid rain and haze
- Explain how the greenhouse gases carbon dioxide and methane cause global warming, (Some examples include:
  - a. the absorption, reflection and emission of thermal energy
  - b. reducing thermal energy loss to space



- Describe the role of sulfur in the formation of acid rain and impact on the environment. Describe the strategies to reduce the effects of major environmental issues (some examples include:
  - a. climate change: planting trees, reduction in livestock farming, decreasing use of fossil fuels, increasing use of hydrogen and renewable energy, e.g. wind, solar.
  - b. Acid rain: Use of catalytic converters in vehicles, reducing emissions of sulfur dioxide by using low sulfur fuels and flue gas desulfurization with calcium oxide).
- Describe the role of NO and NO<sub>2</sub> (subscript) in the formation of acid rain, both directly and through their catalytic role in the oxidation of atmospheric sulfur dioxide.
- Explain how oxide of nitrogen form in car engines and describe their removal by catalytic converters, e.g.  $\text{CO} + 2\text{NO} \rightarrow 2\text{CO}_2 + \text{N}_2$
- Define photosynthesis as the reaction between carbon dioxide and water to produce glucose and oxygen in the presence of chlorophyll and using energy from light.
- Analyze how to use tools to reduce personal exposure to harmful pollutants (some examples include the usage of masks, air quality indices and CO detectors).
- Identify high risk situation in life including those where long-term exposure to these pollutants can lead to respiratory issues and reduction in quality and longevity of life.

## Introduction

The branch of Chemistry which deals with the study of chemicals and other pollutants in the environment is called **environmental chemistry**. It also covers the adverse effects of these chemicals on living and non-living things.

Environmental chemistry is a part of environmental education. The objective of which is to enlighten the people. Particularly the students, about the importance of protection and conservation of our environment. The need for this environmental education, both formal and non-formal, is keenly felt at the national level.

Since the start of industrial revolution, human activities have played havoc with the atmosphere of the earth. The gases which are released due to the increasing use of fossil fuels (natural gas, coal and petroleum) have polluted the atmosphere upto such an extent that it is difficult to breathe air in some areas of metropolitan cities.

The excessive use of fertilizers, insecticides and pesticides, etc. for agriculture purposes has proved to be harmful for animals, birds and human beings. The situation is turning serious for every passing day and there is an urgent need to control the emission of pollutants to the atmosphere.

## 10.1 Composition Of Atmosphere

Earth is covered with a blanket of air called the "atmosphere" which is made up of several layers of gases. Air is essential for life on earth, for animals to breathe and for plants to make their food. You cannot see, smell or taste earth's atmosphere. It contains more nitrogen than any other gas.

The components of the atmosphere may be divided into major and minor constituents. The amount of these different gases in the air varies slightly from place to place, season to season and day to night. The percentages of these constituents by volume are given in Table (10.1).

Table (10.1): Major and Minor Constituents of the Atmosphere

Major Constituent	Percentage	Minor Constituent	Percentage
Nitrogen	78.0	Carbon dioxide	0.03
Oxygen	21.0	Noble gases	About 1.0
		Water Vapours	Variable

### Exercise

- Which method is used to separate gases present in the air?
- Which gas is released when fizzy drinks open?

### Interesting Information!

Environmental science helps us to understand the complex interactions that occur in our ecosystems and the impacts on human life.

## 10.2 Air Pollutants

Any substance (solid, liquid or gas) in the air which has adverse effect on human health, quality of life and natural functioning of ecosystem is called an air pollutant.

The concentration of a pollutant is expressed in parts per million (ppm). A concentration of one ppm means one part of pollutant per million part of solid, liquid or gas mixture in which the pollutant is formed.

### Every Individual should try to.....

Pour liquid waste into sewers not in open drains, river and sea. Stop using chlorofluorocarbon (CFCs) products.

### Major Air Pollutants

Air is not always as pure as it should be. There are five types of harmful substances which account for more than 90% of air pollution. These are fast growing sources of air pollution created by our day-to-day activities. The detail of these substances is mentioned below.

- (i) Carbon dioxide ( $\text{CO}_2$ )
- (ii) Carbon monoxide (CO)
- (iii) Oxides of nitrogen ( $\text{NO}$ ,  $\text{NO}_2$ ) collectively referred to as  $\text{NO}_x$
- (iv) Oxides of sulphur ( $\text{SO}_2$ ,  $\text{SO}_3$ ) collectively referred to as  $\text{SO}_x$
- (v) Hydrocarbons (Methane, ethane etc.)
- (vi) Particulates (Dust, pollens, metallic compounds)
- (vii) Ozone ( $\text{O}_3$ )
- (viii) Smog (Mixture of smoke and fog)

### Sources of Air Pollutants

Millions of tonnes of pollutants are emitted into the atmosphere each year as a result of human activities. The major activity among them is the complete and incomplete combustion of fossil fuels which alone is responsible for most of our pollution problem.

Burning of fossil fuels (oil, natural gas, coal) produce carbon dioxide, carbon monoxide,  $\text{NO}_x$ ,  $\text{SO}_x$ ,  $\text{CH}_4$ , ash, smoke and suspended particles.

Many of these pollutants are also released into the air by natural processes e.g., volcanic eruption releases large quantities of  $\text{CO}_2$ ,  $\text{SO}_2$  and particulates. Methane is released in the air by the decomposition of vegetation. It is also present in waste gases produced during digestion in animals.

Rapid growth of population, urbanization, industrialization and transportation are the main factors which are responsible for environmental pollution. All these factors are increasing in every city of the world especially in the last half century. These pollutants are affecting the environment very badly.

Another pollutant ozone ( $\text{O}_3$ ) is formed when heat and sunlight cause chemical reaction between oxides of nitrogen ( $\text{NO}_x$ ) and volatile organic compounds (hydrocarbons).

An extremely ugly pollutant, smog, is suspended in many cities of Pakistan especially in winter. Its suspension is caused by a combination of factors which include industrial pollution, vehicle emission and crop burning. These factors are responsible for the accumulation of nitrogen oxides, sulphur dioxide, particulate matter and volatile organic compounds in air.

The following Table (10.2) shows the major air pollutants and their harmful effects on human beings and on the environment.

**Table (10.2) Pollutants and Their Harmful Effects**

No.	Pollutants	Harmful Effects
1	Carbon dioxide (CO <sub>2</sub> )	Higher levels of carbon dioxide lead to increased global warming which can cause ice caps to melt and oceans to warm, causing sea levels to rise. Extreme weather changes such as heat waves, heavy rains and wild fires also occur.
2	Carbon monoxide (CO)	It is extremely poisonous gas that can cause suffocation and death. Carbon monoxide is very toxic gas that stops the red blood cells in animal's blood from carrying oxygen that body needs.
3	Oxides of nitrogen (NO <sub>x</sub> ) NO, NO <sub>2</sub>	NO <sub>x</sub> can damage lungs, irritate the eyes and damage vegetation. It can also cause acid rain which affects buildings and statues made of limestone.
4	Oxides of sulphur (SO <sub>x</sub> ) SO <sub>2</sub> , SO <sub>3</sub>	SO <sub>x</sub> irritates the eyes and causes breathing difficulties and acid rain.
5	Hydrocarbons	Poisonous and cause global warming.
6	Particulate matter	Irritates the eyes and can also cause severe breathing problems for people with asthma. It also makes clothes dirty. Also, visibility is reduced because it produces haze in the air. It may render lakes and streams acidic.

7	Ozone	Breathing ozone can cause a variety of health problems including chest pain, coughing, throat irritation and congestion.
8	Smog	It can lead to health complications like allergies, asthma and lung infections. Inhibits the proper growth of plants.

#### Amazing Facts about the Environment

1. 78% of marine mammals are at risk of choking on plastic.
2. Human use only 1% of all available water.
3. The world has over 3.04 trillion trees. 27000 out of them are cut down daily to make toilet paper.

#### Exercise

How does air pollution affect plants?

### 10.3 Acid Rain

**When rain water has pH less than 5.6, it is known as acid rain.** In 1852, Robert Angus Smith was the first to show the relationship between acid rain and atmospheric pollution in Manchester, England. He is sometimes referred to as the "Father of Acid Rain". Burning of fossil fuels releases harmful gases into the atmosphere. These gases ( $\text{SO}_2$ ,  $\text{SO}_3$ ) are produced due to the presence of sulphur in the fossil fuels.  $\text{SO}_2$  is converted to  $\text{SO}_3$  in the presence of oxides of nitrogen of the atmosphere. Oxides of nitrogen are produced mostly by the direct combination of atmospheric oxygen and nitrogen in the industrial and domestic combustion processes. They are also produced by the combination of atmospheric nitrogen and oxygen in the presence of lightning. Significant amount of nitrogen oxides is produced by the reactions taking place in automobile engines Fig.(10.1).

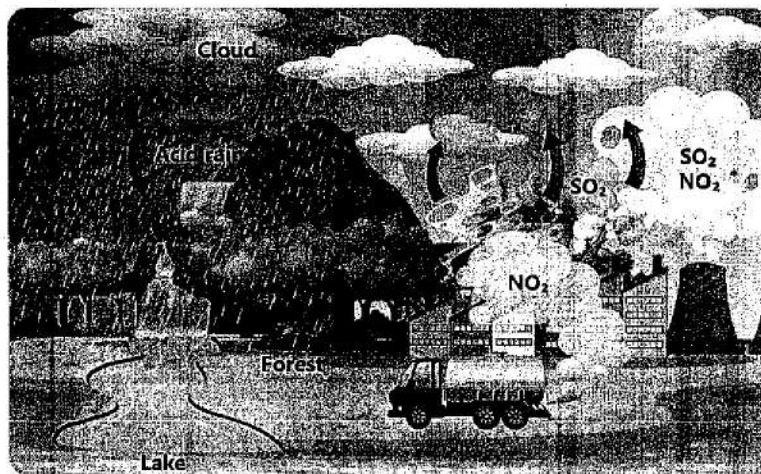
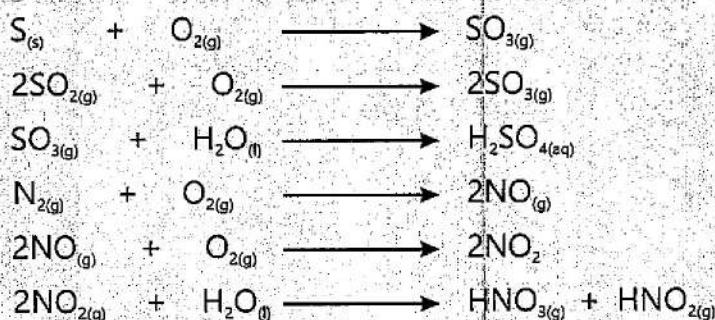


Fig (10.1): Acid rain usually falls far from the site where the acidic oxides are generated.

These gases mix with the moisture that is always present in the air to form acid droplets. Wind can carry these acidic droplets to huge distance.

Finally, these droplets return to the ground as acid rain, acid hail, snow and even fog. Acid rain looks, feels and tastes like clean rain. Its corrosive nature causes widespread damage to the environment.



#### Interesting Information!

There is a giant floating patch of garbage spread over in the Pacific Ocean. It contains about 100 million tons of garbage.

### Effects of Acid Rain

Acid rain causes a number of adverse effects. It tends to increase acidity of the soil, threatens human and aquatic life, destroys forests, and reduces agricultural productivity. Besides, it can corrode buildings, monuments, statues, bridges and railings. Most important adverse effects of acid rain are as follows:

#### (i) Soil

Acid rain makes soil more acidic. It dissolves and washes away nutrients present in the soil which are needed by plants. It can also dissolve toxic substances such as aluminium and mercury which are naturally present in the soil.

#### (ii) Plants

Many plants cannot live or grow in acidic soil. It can damage vegetation and plants. Tree roots hold the soil together on hills and mountain areas. If the trees are destroyed then the soil is washed away and new plants cannot grow there.

#### (iii) Aquatic Life

Acid rain falls into drains, streams, lakes, marshes, rivers and damages the aquatic life. Acid rain can make water too acidic for animals to live in. Due to this, many lakes and rivers no longer have fish.

#### (iv) Human Health

The acidification of surface water does not affect life directly. However, toxic substances leached from the soil can pollute land water supplies and damage human health.

#### (v) Agriculture

Crops are less affected by the acid rain than forest. Farmers can prevent acid rain damage by monitoring the conditions of the soil and when necessary adding crushed lime to neutralize the acid.

#### (vi) Human-made Structure

Acid rain and the dry deposition of acidic particles damage buildings, statues, automobiles, and other structures made of stone, metal etc. Historical buildings like Parthenon in Athens (Greece) and the Taj Mahal in Agra (India) are deteriorating due to acid rain.

#### Exercise

- Which acids are made when  $\text{SO}_2$  and  $\text{NO}_2$  dissolve in rain?
- What happens to the soil if trees are destroyed by acid rain?

## 10.4 Global Warming (Greenhouse Effect)

The progressive warming up of the Earth's surface due to blanketing effect of man-made carbon dioxide, methane and other gases in the atmosphere is called Greenhouse Effect.

The sun emits short wave radiation that passes through greenhouse gases to heat the surface of the Earth. At night, the hot Earth's surface emits longwave radiation that is mostly absorbed by greenhouse gases. This process of absorption prevents the radiation to reach space, reducing the speed at which the Earth can cool off (Fig 10.2).

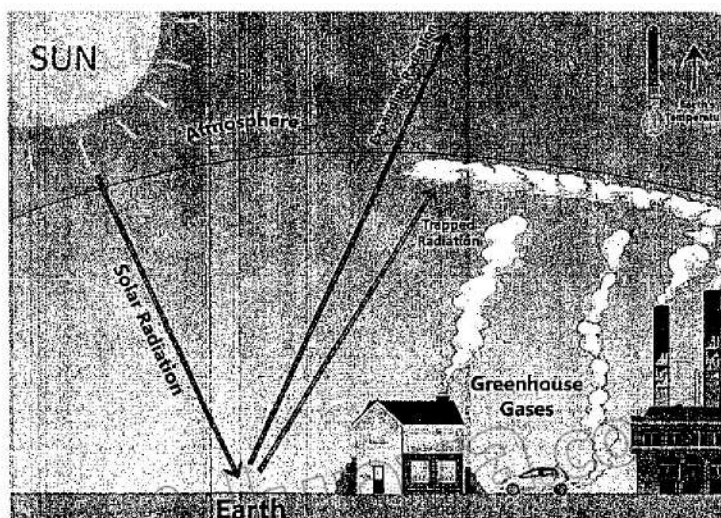


Fig 10.2: Global warming/greenhouse effect



Higher the concentration of carbon dioxide and other gases, greater will be the absorption of thermal and radiation the increase in global warming.

### Do you Know?

Greenhouse effect, depletion of ozone and acid rain are the global effects of pollution.

## Sources of Greenhouse Gases

Due to the burning of the large amount of coal, oil and natural gas, the amount of greenhouse gases, carbon dioxide together with other gases in the atmosphere has increased for the last 300 years. About half of this carbon dioxide is utilized by plant life during photosynthesis. As human beings cut down forests, the capacity of the trees to remove  $\text{CO}_2$  from the air is diminished.

Methane is another greenhouse gas which causes adverse effects. The increase in its concentration in air is due to the increased decay of vegetation matter, digestion in animals and increased farming of the rice fields.

Sunlight passes through the greenhouse gases and warms everything on the Earth

The Earth warms up and gives out heat. Some heat pass through the greenhouse gases but some are trapped inside, warming up the Earth.

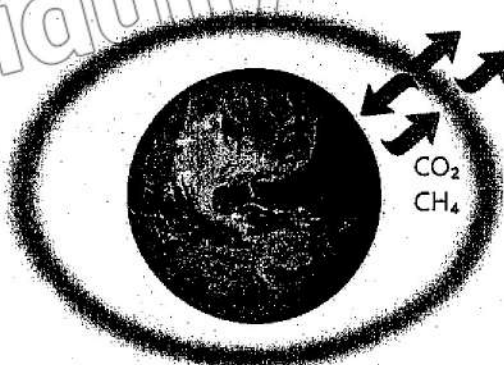


Fig (10.3): GREENHOUSE GASES

### Interesting Information!

Water vapours also act as greenhouse gas. When released into the atmosphere, water soon comes back to earth as acid rain.

The remaining carbon dioxide goes on accumulating in the lower areas of the atmosphere and forms a thick dense layer. This layer behaves like glass sheet of greenhouse that allows the incoming solar radiation but does not allow it to escape outside; as a result of this the average temperature of the Earth rises.

A rise of a few degrees in temperature may seem small, but it can be enough to cause significant changes in the climate. At the moment, it is difficult for scientists to say how big the changes will be and where the worse effects will occur. This can damage agriculture and food production as well.

### Exercise

- How do living things add and plants remove carbon dioxide from the air?
- Which gas do rice plants produce?
- Which gas is given out by rotting garbage?

The effects of climate change may be physical, ecological, social or economic. Following are four adverse effects of the global warming.

### Sea level

Higher temperature will make the water of the seas and oceans expand. Ice melting in the Antarctic and Greenland will flow into the sea and it results in higher sea levels. This phenomenon will threaten the low-lying coastal areas of the world such as the Netherlands and Bangladesh Fig (10.4).



Fig (10.4): Global warming at sea level

### Increase in Rainfall

There may be enormous increase in rainfall which may increase the sea level. This ultimately will cause worldwide floods endangering survival of living species. Fig (10.5).

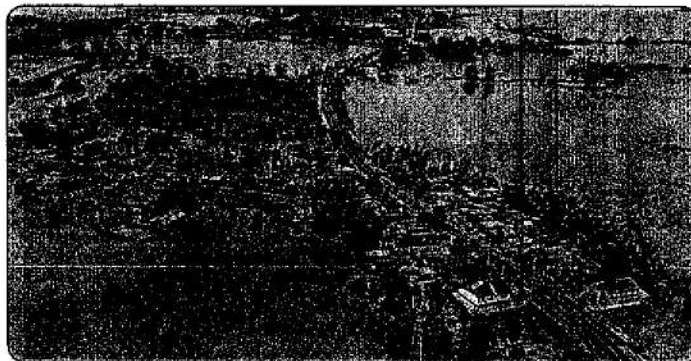


Fig (10.5): Effects of Climate Change

### Effects on Agriculture

The changes in the weather will affect the types of crops grown in different parts of the world. Some crops such as wheat and rice grow better in higher temperature but other plants such as maize and sugar cane do not Fig (10.6).



Fig (10.6): Global warming risking the agriculture drought.

### Hot Summer and Winter

In moderate region, the winter will be shorter and warmer and the summer will be longer and hotter Fig (10.7).



#### Interesting Information!

Since 1990, we have lost around 28 trillion tons of ice. At presents, its melting rate is 1.2 trillion tons per year.



Fig (10.7): Summer and winter

## 10.5 Strategies to Reduce Environmental Issues

Huge amount of pollutant gases are thrown out in the atmosphere by burning fossil fuels. Automobiles, aeroplanes, industrial machines and coal-fired electricity generating plants, etc. are mainly responsible for the extremely polluted air especially in big cities. Scientists have developed a number of different ways to control this menace of pollution.

Planting trees is thought to be very helpful in removing the air pollution. A well-known process carried out by plants is photosynthesis in which plants clean the air through absorption of carbon dioxide and releasing oxygen. This famous reaction takes place in the presence of sunlight and it is catalysed by chlorophyll, the green pigments present in leaves.



The particulate matter present in the atmosphere is also removed by plants when it deposits on leaves, branches and trunk surfaces.

Catalytic converters are used in the exhaust system of modern-day automobiles to reduce the emissions from an internal combustion engine. Due to non-availability of enough oxygen the carbon fuel in engine does not burn completely into carbon dioxide and water. Thus, toxic by-products like CO and hydrocarbons are produced.

A three-way catalytic inverter performed the following three functions simultaneously.

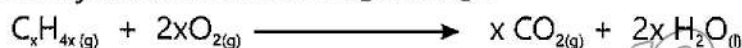
1. It reduces nitrogen oxide into elemental nitrogen and oxygen.



2. It oxidizes CO to CO<sub>2</sub>



3. It oxidizes hydrocarbons into CO<sub>2</sub> and H<sub>2</sub>O



Similarly, the emission of sulphur dioxide can be decreased either by using fuels which have significantly less sulphur contents or using flue gas desulphurization process. This process can remove sulphur dioxide gas from the exhaust gases of fossil fuel. Flue gas is the emitted material produced when fossil fuels are burnt in power plants. The desulphurization process involves the addition of absorbents like calcium oxide which can remove upto 95% of the sulphur dioxide from the flue gas.

To discourage the excessive use of fossil fuels in our daily lives it is urgently required to use the renewable resources to meet our energy needs. Renewable resources are those resources that can continue to exist despite being consumed over a period of time even as they are used.

These resources include Sun, wind, water, geothermal, biomass and hydrogen gas. Solar energy and wind energy have been proved to be very effective ways of generating electricity without damaging the environment.

## How to avoid harmful effects of air pollution?

Air quality index (AQI) is a rating system that shows how bad is the atmosphere around you. An (AQI) value under 50 is considered good in quality. This means that it is safe for you to spend time outdoors without posing a risk to your health. As the (AQI) number increases, so does the risk to health. An (AQI) over 300 is considered hazardous. Children under 18, adults over 65, people with chronic heart or lung disease and diabetic people are high risk groups. Outdoor workers can also be considered at higher risk because of prolonged exposure.

### The following steps should be taken when air quality is bad.

1. Reduced the time you spend outdoors. Also reduce the intensity of outdoor activity. According to experts the chances of being affected by unhealthy atmosphere increase the longer a person is active outdoors and the more laborious the activity.
2. If you are forced to go out, then consider wearing a mask. Unfortunately, not all the mask provides adequate safety against particulate matter. Cloth or dust mask may not effectively filter out the finer particles. However, well fitted N95 masks have better filtration capabilities and may be safer to use.
3. Keep your indoor healthy by keeping the windows and doors closed. If it is difficult to maintain clean air in the entire room then create a clean room by switching on air conditioner or air cleaner.
4. If you experience such symptoms that worry you, talk to your doctor.
5. Install carbon monoxide detector to detect the increased level of carbon monoxide. These higher levels of CO may occur due to faulty fuel burning appliances.

Breathing in polluted air by these high risk groups may affect their lungs, heart and brain. Air pollutants can enter their blood stream and can cause coughing or itching of eyes which may lead to poor quality of life, hospitalization, cancer or even premature death.

### Key Points

1. Earth is covered with a blanket of air called atmosphere which is made up of several layers of gases.
2. Any substance in the air which has an adverse effect on human health, quality of life and natural functioning of the ecosystem is called a pollutant.
3. Oxides of carbon, nitrogen and sulphur along with methane and particulate matter are the main pollutants in the air.
4. Major sources of pollutants are due to human activities especially the burning of fossil fuels.
5. Pollutants have extremely adverse and harmful effects not only on the human beings but on the whole ecosystem.
6. Acid rain is formed due to the presence of oxides of nitrogen and sulphur when they are mixed with the moisture present in the atmosphere.
7. The progressive warming of Earth's surface due to blanketing effect of  $\text{CO}_2$ ,  $\text{CH}_4$  and other gases present in the atmosphere is called green house effect. This effect has increased the temperature of the Earth.
8. Every effort should be made to reduce the harmful effects of the pollutants. These efforts include discouraging the use of fossil fuels, planting trees and using the renewable sources of energy.
9. Steps should be taken to avoid the harmful effects of pollution especially on the people who are at higher risk.

### Exercise



#### 1. Tick (✓) the correct answer.

- (i) Which gases are responsible for greenhouse effect?  
(a)  $\text{SO}_x$ ,  $\text{NO}_x$  (b)  $\text{CO}_2$ ,  $\text{CO}$   
(c)  $\text{CO}_x$ ,  $\text{CH}_4$  (d)  $\text{O}_2$ ,  $\text{O}_3$
- (ii) Indicate the source of sulphur which is responsible for the presence of oxides of sulphur in the atmosphere.  
(a) Decomposition of vegetation  
(b) Waste gases from digestion of animals  
(c) Photochemical of smog  
(d) Combustion of fossil fuels
- (iii) Concentration of which gas in the atmosphere is decreased by photosynthesis in plants?  
(a) Oxygen (b) Nitrogen  
(c) Carbon dioxide (d) Water vapour

- (iv) Which substance remains unaffected in the catalytic converter fixed in the exhaust of the automobiles?  
(a)  $\text{CO}_2$  (b) CO  
(c) NO (d)  $\text{NO}_2$
- (v) People of which age groups are the most affected by the air pollution?  
(a) Young adult  
(b) Cancer patient  
(c) Children  
(d) Both children and aged people
- (vi) In which area there is a greater possibility of acid rain?  
(a) Around village (b) Around big cities  
(c) Around industrial area (d) Around water bodies
- (vii) Why is smog not felt in summer?  
(a) Because fog is not present in summer  
(b) Because due to heat of the earth the smoke rises up  
(c) Because in summer smoke and fog cannot mix with each other  
(d) Because less fossil fuels are burnt in summer
- (viii) Which catalyst is used in the catalytic converter fixed in the exhaust systems of automobiles?  
(a) Ni (b) Cu (c) Pt, Pd and Rh (d) CaO
- (ix) Which components are essential for the formation of photochemical smog?  
(a) CO,  $\text{NO}_2$ ,  $\text{CO}_2$   
(b)  $\text{NO}_2$ , volatile organic compounds, sunlight  
(c)  $\text{CO}_2$ ,  $\text{NO}_2$ , sunlight  
(d) volatile organic compounds,  $\text{NO}_2$ , CO
- (x) Which air pollutant can cause respiratory problems?  
a)  $\text{CO}_2$  b) Ozone c) Smog d) CO

## 2. Questions for Short Answers

- i. What is the main objective of environmental education?
- ii. How is particulate matter released in the atmosphere?
- iii. Which gas is more poisonous,  $\text{CO}_2$  or CO?
- iv. How does acid rain affect forests?
- v. In what way sulphur present in fossil fuels becomes dangerous?
- vi. Name any three major sources responsible for the greenhouse effect.
- vii. How is geothermal energy useful for us?

### 3. Constructed Response Questions

- i. How is the excessive use of insecticides and pesticides harmful for birds?
- ii. Percentage of  $\text{CO}_2$  in air is only 0.03%. Then how does it become harmful for the ecosystem?
- iii. Why only some pollutant gases present in the atmosphere cause green house effect while others do not?
- iv. How can you reduce the emission of CO present in the gases emitted by the burning of fuel in the automobile engines?
- v. Mention three different ways in which solar energy can be useful for us.

### 4. Descriptive Questions

- i. Describe the harmful effects of the major pollutants present in the air.
- ii. Explain greenhouse effect. How is global warming dangerous for us?
- iii. What is air quality index? What information does it convey?
- iv. Who are at high risk groups and why is pollution more dangerous for them?
- v. Describe three strategies to address environmental issues.

### 5. Investigative Questions

- i. Major Pakistani cities experience a very high AQI in winter which renders them the most polluted cities in the world. Point out some of the major causes of high AQI in these cities.
- ii. Why does AQI not rise in Pakistan in hot days of summer?
- iii. How has climate change affected Pakistan during the last five years?