UNIT 2 AIR POLLUTION

Structure

2.0 INTRODUCTION

In the first unit of this block you have studied about the nature of atmosphere and various types of environmental reactions that occur in the atmosphere. Present day atmosphere has changed with the onset of the industrial revolution. Previously everybody heard about atmosphere consistting of various gases with major constituents like nitrogen(78.08%), oxygen(20.95%), argon(0.93%), CO_2(0.04%), water vapor(0-4%) and trace gases including ozone, helium, hydrogen, nitrogen oxides, sulfur dioxide. It is learnt that in addition to these gases, microscopic liquid and solid particles like dust, pollen grains, carbon particles, sea salt and microorganisms collectively known as aerosols are carried up to the atmosphere from land and water surfaces. In this unit you will study the role of these constituents in the atmosphere and learn about the chemical processes that explain how and why the atmosphere is getting polluted. The unit also deals with how the natural properties of air pollutants are influenced by external factors and the environmental medium where these exist. In the next section we will begin with defining air pollution.

2.1 OBJECTIVES

After studying this unit you should be able to:

- define air pollution;
- enlist the sources of common air pollutants;
- classify various types of air pollutants; and
- describe the effects of air pollution.

2.2 AIR POLLUTION: DEFINITION

By definition air pollution is the presence of contaminants or pollutants in the air like noxious gases, particles of solid and particulates of liquid matter in high concentrations that interfere with human health or welfare, or produce other harmful environmental effects (US-Environmental Protection AgencyUS-EPA). In other words, any substance in the atmosphere which can create harm to the natural environment and human beings is known as air pollutant.. The level of air pollution can be determined by three factors given below.

1. The quantity of pollutant that is present in the air
2. The area in which the pollutants are dispersed
3. The removal process of pollutants from the air

Let us first of all study the common pollutants in air and their sources.

2.3 AIR POLLUTION: DEFINITION

On the basis of adverse effects of air pollutants like impaired health, destroying the environmental resources and damaging property, as per the clean air act of 1970,the sources of air pollutants can be classified as follows:

1. **Mobile Sources**: Mobile sources of air pollution start with the exhaust from the vehicles that contains notable pollutants like lead particulates, carbon monoxide, carbon dioxide, hydrocarbons, and oxides of nitrogen, and small amounts of sulfur oxides. These pollutants generate secondary pollutants when react in the atmosphere and adversely impact on the environment like photochemical smog and acid rain.

2. **Stationary Sources:** Stationary sources are two types: point sources and rea sources

   Point sources: These include some of the most important stationary sources like furnaces and the combustion of carbonaceous fuels, boilers, ovens and dryers, process systems which produce volatile chemicals, gases, etc.

   Area sources: Solvents from solvent-based paints, leaking pipe joints, maintenance work involving the dismantling of pumps or breaking of pipeline spills, unloading /loading procedures and contaminated ground come under this type of sources.

3. **Fugitive Emissions**: Fugitive emissions are those which escape from a process rather than being discharged. They enter the atmosphere untreated

by which they show adverse effects. These emissions can be reduced by implementing standard operating procedures but natural emissions are impossible to control. For example: industrial sources, dry cleaning, agricultural practices, natural sources like volcanoes, forest fires.

The particulate matter (PM), ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and lead (Pb) are some of the air pollutants about which you would study in the following paragraphs. The sinks (place of absorption or dispersal) of some of these pollutants are also given here.

1. **Particulate matter:** The particulate pollutants mean very minute solid or liquid particles. They may be different in size and shape, also in physical and chemical properties. These can be either natural or man made. The major sources are stack emissions, construction work, unsealed roads etc., Since they are very small in size they provide surface for many reactions for the formation of secondary pollutants and also diffuse light by which reduce visibility. The particulate pollutants are classified as:

a. **Dust**: These are solid particles with >100¼m in diameter dispersed into the air.

b. **Fume**: These are solid particles from factories and industries usually between 0.03- 0.3 ¼m in diameter. Example: metallic oxides

c. **Mist**: These are liquid particles with 0.5-3.0 ¼m in diameter formed by condensation reactions.

For example: $SO_3 + H_2O \longrightarrow H_2SO_4$

d. **Smoke**: These are solid particles between 0.5-1.0 ¼m in diameter produced by incomplete combustion of carbon containing material.

e. **Spray**: These are liquid particles which are formed by the process of atomization.

If the size of the particulate matter is >3 μm, these are negatively charged where as particles with < 0.01 μm size are positively charged. These electrical charges will have considerable effect on the rate of coagulation and deposition. Once the particulate matter releases into the atmosphere it undergoes many physical and chemical changes like increase in size, absorb or desorb gases, change in electrical charge, colloid or cohere with other particles, change in specific gravity, converting into sulpahate and nitrate aerosols .Due to this the pH, chemical reactivity, and toxicity changes dramatically that affects the life time of these particles in the atmosphere.

For example: Polycyclic aromatic hydrocarbons (PAH). PAHs are generated by coal furnace (>1 μm), cigarette smoke (0.1 μm) and chemical reactions involving ethene and ethane > 500^0C.

2. Carbon Monoxide

Carbon monoxide is a colurless, odourless and tasteless gas found in abundance, around 530 million tonnes (about 0.00001%), with an average residence time of 36 to 100 days. The natural existence of atmospheric CO is due to volcanic eruptions, photolysis of methane and terpenes, forest fires, chlorophyll decomposition, and microbial action in oceans.

It enters the atmosphere by anthropogenic sources like transportation, disposal of solid waste, burning of agricultural waste, steel production, etc. It is also emitted directly into the atmosphere by inefficient combustion of fossil fuels.

$$2C + O_2 \longrightarrow 2CO$$

Sink: The CO in the atmosphere by anthropogenic and natural sources will be naturally removed from the air by conversion to CO_2 in a sequence of chemical reactions either by aerial oxidation or soil microorganisms.

$$2CO + O_2 \longrightarrow 2CO_2$$

3. Carbon dioxide

In the natural atmosphere carbon dioxide is generated by the combustion of organic matter, weathering or biological decomposition.

CO_2 acts as thermal absorber by which it can absorb energy from infrared (IR) radiationThe energy from the incoming IR photon causes the CO_2 molecule to vibrate and the extra energy has been removed by the emitted photon in a continuous process. This potential of CO_2 to absorb and re-emit infrared energy makes this gas an effective heat-trapping greenhouse gas. The gases like nitrogen (N_2) and oxygen (O_2) are not able to absorb infrared photons because of lack of vibration. The details of greenhouse gases and the importance of greenhouse effect have already been discussed in the previous unit. **Sink:** Because of its nature of solubility in water, the major sink for CO_2 is ocean where 50% of all anthropogenic emissions are getting absorbed. The forests also serve as a sink.

4. Sulfur Compounds

Number of sulfur compounds are released into the atmosphere from both natural and anthropogenic sources. The major sources are from volcanic eruptions and man made emissions like incomplete combustion of fossil fuels.

The common sulfur compounds exist in the atmosphere is SO_2, SO_3, H_2S and H_2SO_4. Combustion of fossil fuels and roasting of metal sulfide ores are the anthropogenic sources. Out of these sulfur trioxide (SO_3) is directly emitted in ore smelting and fossil fuel combustion and also by the oxidation of SO_2 and readily soluble in water to produce H_2SO_4 which is known as **acid rain**. The reactions of formation are as follows.

$$\mathbf{S + O_2 \longrightarrow SO_2}$$

$$\mathbf{2\,SO_2 + O_2 \longrightarrow 2SO_3}$$

$$\mathbf{SO_3 + H_2O \longrightarrow H_2SO_4}$$

It is estimated that100-130 million tonnes of SO_2 per year enter the atmosphere through anthropogenic activities and 50-70 million tonnes are released from natural sources like volcanoes, sea spray and microbial activities.

Sink:

The removal process of SO_2 from the atmosphere is by both dry and wet deposition. SO_2 dissolves in water to form a dilute solution of sulfurous acid (H_2SO_3). This sulfurous acid remains in clouds, rain droplets or at the surface.

A portion of the SO_2 is converted into H_2SO_4 by its gas-phase oxidation with subsequent aerosol formation by nucleation or condensation. Sulfuric acid reacts with ammonia (NH_3) to form ammonium hydrogen sulfate (NH_4HSO_4), ammonium sulfate [$(NH_4)_2SO_4$] or mixed salts with ammonium nitrate (NH_4NO_3) salts.

The atmospheric SO_2 is converted to sulfate aerosol in other process and is removed from the atmosphere by dry and wet deposition processes.

5. Nitrogen Compounds

The most abundant gas in the atmosphere is nitrogen with 78.09% abundance. The major gaseous forms of nitrogen in the atmosphere are molecular nitrogen (N_2), nitrous oxide (N_2O), nitrogen dioxide (NO_2), nitric oxide (NO) and ammonia (NH_3). The details of these gases and their role in pollution are explained here.

Nitrous Oxide

It is a natural constituent of the air in the atmosphere with concentration of 0.30 ppm. It acts as a strong oxidizing agent. It is also called laughing gas because of its euphoric effects. It is produced in the soil by anaerobic bacteria. It generates NO in the stratosphere by photolytic dissociation.

Nitric Oxide

Nitric oxide is generated naturally by anaerobic processes in soil and water, by combustion processes and by photochemical destruction of nitrogen compounds in the stratosphere. The major man made sources are automobile exhaust, combustion of fossil fuel-fired electric generating stations, industrial boilers, incinerators and home heaters.

Nitrogen Dioxide

Nitrogen dioxide is light yellowish orange at low concentrations and brown at high concentrations. It is produced by the direct oxidation of NO in the atmosphere as per the following reaction.

$$2NO + O_2 \longrightarrow 2NO_2$$

It can also be generated by photochemical reactions of O_3, peroxy radical (RO_2), hydroxyl radical(OH)•, hydroperoxide radical (HO_2) and H_2O_2. Therefore, higher NO_2 levels occur on sunny days. Some of the important reactions are shown below.

$$NO + O_3 \longrightarrow NO_2 + O_2$$

$$RO_2 + NO \longrightarrow NO_2 + RO$$

$$HO_2 + NO \longrightarrow NO_2 + OH$$

Sink:

The significant sink for NO is its conversion by direct oxidation and photochemical processes to NO_2. A major sink for NO_2 is its conversion to nitric acid as is shown below.

$$OH\bullet + NO_2 + M \longrightarrow HNO_3 + M$$

Where M is a species which absorbs energy (generally O_2 or N_2).

$NO_2 + O_3 \longrightarrow NO_3\bullet + O_2$

$NO_2 + NO_3\bullet \longrightarrow N_2O_5$

$N_2O_5 + H_2O \longrightarrow 2HNO_3$

Nitrogen dioxide reacts with ozone to produce nitrate free radical (NO_3).The nitrate free radical further reacts with nitrogen dioxide to give dinitrogen pentaoxide (N_2O_5). This react with water swiftly to produce HNO_3. HNO_3 reacts with ammonia (NH_3) or other alkaline species to form salts like NH_4NO_3.The nitrate aerosol is removed from the atmosphere either by dry or wet deposition processes known as **acid deposition** or **acid rain** like in the sulphate aerosol.

Lead: Lead is a significant heavy metal air pollutant. The exhaust of the vehicles which use leaded petrol is the primary source of this pollutant. It is used as a fuel in the form of tetraethyl lead (Pb $(C_2H_5)_4$) to aid even combustion. The reaction is as follows:

Pb $(C_2H_5)_4$+O_2+Petrol (Halogenated organic compound $\longrightarrow$ CO_2+H_2O+$PbCl_2$+PbBrCl+$PbBr_2$

Other major sources of lead in the air are waste incinerators, processing of ore and metals, aircraft operating on leaded aviation fuel, utilities, lead-acid battery manufacturers, lead smelters, lead-based paints, ceramics, pipes, plumbing materials, solders, gasoline, batteries, ammunition and cosmetics.

Now you can assess your understanding about the sources of air pollutants by trying to answer the following questions. After this you will study the types of air pollutants in the next section.

Check Your Progress 1

1. Fill in Sources of the following air pollutants

   a. Ozone

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   b. Nitrogen Dioxide

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   c. Carbon Dioxide

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2.4 TYPES OF AIR POLLUTANTS

There are different types of air pollutants depending on how and where these are generated . These are listed below and explained in the following subsections.

Natural and Anthropogenic Pollutant

Primary and Secondary Pollutants

Outdoor and Indoor Pollutants

Stationary and Mobile Source Pollutants

2.4.1 Natural and Anthropogenic Pollutants

The pollutants which are released by the natural sources such as eruption of volcanoes, sea sprays, lightning and microbial processes are called **natural pollutants**. Where as pollutants released by human activities such as industrial and vehicular emissions are known as **anthropogenic pollutants**.

The sources for natural pollutants are listed below:

1. Biogenicsources-: soil micro organism, hydrosphere organism, vegetation and animals.
2. Geophysical sources- soil dust and sea salt
3. Geochemical sources- volcanism, burning of biomass and lightening

The anthropogenic sources are:

1. Biogenic sources- Agriculture
2. Chemical sources- chemical processes, high temperature processes and combustion
3. Physical processes -dust resuspension and volatilization

2.4.2 Primary and Secondary Air Pollutants

The pollutants which are released directly into the atmosphere from a particular source of pollution which means they are the direct products of evaporation and combustion. Example: CO, CO_2, CH_4, NO, N_2O, NH_3, H_2S, SO_2, chlorides, fluorides, bromides and participate matter/aerosols.

The carbon particulate matter is released into the atmosphere by burning of fuels and wastes. In addition to this incomplete combustion of fuel molecules releases in to the atmosphere as Volatile Organic Compounds (VOC).The nitrogen gas in the air gets oxidize during combustion at high temperatures and releases various nitrogen oxides (NO_x).The pollutants like sulfur oxides are release into the atmosphere by burning of coal. Coal contains 0.2-5.5% sulfur and heavy metal impurities like mercury.

Source: Industry or vehicles

Effects: Photochemical smog **Secondary Air Pollutants**

The primary pollutants which can under go further reactions by light energy, heat or the presence of other chemicals and get converted into undesirable toxic compounds are called **secondary pollutants**.

Example: Ozone is a secondary pollutant which is formed by the photolysis reaction of oxides of nitrogen followed by subsequent reactions with VOCs NO_2, SO_2, HNO_3 and H_2SO_4. formed from SO_2.

Effects:: Acid rain

Some pollutants may act both as primary and secondary pollutants that mean they are both emitted directly and formed from other primary pollutants also.

Some primary and secondary pollutants, their sources and the effects are listed in Table 2.1.

Table 2.1: Some Primary and secondary pollutants, their sources and effects

Primary Pollutants

Name	Symbol	Source	Effect
Suspended particulate matter	PM	Smoke, metal particles, soot from cooking and heating. Dust through wind.	Respiratory ailments, impair lung growth in infants and heart attacks
Volatile organic compounds	VOC	Incomplete combustion of fossil fuels emissions from industries, evaporation of gasoline and solvents	Carcinogenic
Carbon monoxide	CO	Incomplete combustion of fuels	It binds to hemoglobin and block the oxygen delivery tissues
Nitrogen Oxides	NOx	Burning of Nitrogen containing fuels, biomass at high temperatures, lightening and microbial process.	Causes acid rain and Lung irritation
Sulfur Oxides	SOx	Burning of Sulfur containing fuels (coal), volcanoes, sea spray and microbial process.	Causes acid rain and impairs breathing
Lead	Pb	Burning of lead containing fuels and solid waste	Causes brain damage and death
Radon	Rn	Natural breakdown of radium and Uranium containing rocks	Lung cancer
Chlorofluorocarbons causes	(CFC)	**Leakages from refrigerants and the use of aerosols.**	Causes ozone depletion and skin cancer
Secondary Pollutants			
Ozone	O_3	Photochemical reactions of VOCs & NOx	Oxidizes rubber, highly reactive in

			lungs and shows adverse effects on animals and plants
Peroxyacetylnitrates	PAN	Photochemical reactions of VOCs & NOx	Adverse effects on plants, lungs and eyes
Persistent organic pollutants	POPs	Pesticides, solvents and pharmaceuticals	Causes cardiovascular disease and cancer

2.4.3 Indoor and Outdoor Air Pollutants

Dear learner, have you ever thought that one source of pollution could be our own house which is a first indoor environment for a child? This is called indoor air pollution. Let us look into some of the factors which cause indoor air pollution that affects our health. . The causes and the health effects of indoor air pollutants are given in Table 2.2.

Table 2.2: The causes and the health effects of indoor air pollutants

S.No	Cause of indoor air pollutant	Health effect of the pollutant
1.	Inadequate ventilation in poorly ventilated dwellings pollutants will accumulate to higher concentrations than that of outside. This is known as '**Sick building syndrome'.**	Irritations of eyes, nose and throat, dry mucous membranes and skin erythema (reddening or flushing of the skin), rashes, mental fatigue, headache, sleepiness, cough, hoarseness, wheezing, nausea, dizziness, unspecific hypersensitivity reactions
2.	High temperature and humidity	Fatigue, irritability, headache and a decrease in performance and alertness
3.	Combustion of oil, gas, kerosene, coal, wood, and tobacco products.	Bronchoconstriction, lung cancer.
4.	• Building materials: Formaldehyde released from pressed wood products like hard wood, plywood, wall paneling, fibre board and urea-formaldehyde foam insulation. • Radon released from rocks and other building materials under the constructions of homes, schools and offices enters inside with dust. • Asbestos found in materials used in the automotive industry and construction of buildings, ceiling, and floor tiles.	• Irritation in eyes, nose and throat, coughing, skin rashes, headache, dizziness and vomiting. • Radon is a carcinogen. • prolonged exposure causes asbestosis, mesothelioma and lung cancer.

5.	Second hand tobacco smoke/ Environmental tobacco smoke (ETS): releases from burning end of cigarette and smoke exhaled by the smokers.	Respiratory tract infections and lung cancer
6.	Biological pollutants - Mites - Allergens – Molds developed in damp or wet areas such as cooling coils, humidifiers, condensate pans or unvented bathrooms can be moldy draperies, bedding, carpet and other areas where dust collects that may accumulate biological contaminants.	Hypersensitivity, pneumonitis, allergic rhinitis and some types of asthma
7.	Volatile organic compounds(VOCs) emitted from paints, and other solvents, wood preservatives, aerosol sprays cleansers and disinfectants, moth repellents and air fresheners, stored fuels and automotive products· dry - cleaned clothing, pesticides, building materials, furnishings, office equipment such as copiers and printers, graphics and craft materials including glues and adhesives, permanent markers and photographic solutions.	Eye, nose and throat irritation, headache, loss of coordination, nausea,· damage to liver, kidney and central nervous system cancer in animals, some are suspected to cause cancer in humans

Outdoor Air Pollutants

The causes and health effects of outdoor air pollution are given in Table 2.3.

Table 2.3: The causes and health effects of outdoor air pollution

S.No	Cause of outdoor air pollutant	Health effect
1.	Combustion of fossil fuels from domestic heating, power generation and motor vehicles releases primary particles containing sulpahate, metals and polycyclic aromatic hydrocarbons and secondary particles containing nitrogen oxides, sulphur oxides and ozone.	Respiratory morbidity (pneumonia, asthma) Increased mortality (from all causes) Decreased lung growth and function.O_3 causes lung irritation and inflammation, impaired pulmonary function, eye, nose and throat irritation
2.	Industrial processes release nitrogen oxides, CO, sulphur oxides other than dust, fly ash, smoke, fog, soot and fumes	Decrements in lung function, reduces oxygen-carrying capacity, chronic bronchitis, broncho-constriction
3.	Agricultural processes-biological agents like fungi, mycotoxins,	N-ARD, ARD, infections and cancer, Acute respiratory problems.

	glucans, actinomycetes, viruses, microbial enzymes, plant, mammalian and invertebrate proteins. Burning of agriculture waste releases greenhouse gases like N_2O and methane, SPM.	
4.	Waste incineration releases PM containing heavy metals, dioxins, furans, mercury etc.	Autism, Attention Deficit Hyperactivity Disorder (ADHD), lung cancer, dementia damages immune system
5.	Natural processes like volcanic eruptions releases CO_2, SO_2, H_2S, HF, HCl and HBr	Headache, dizziness, increased heart rate, irritation of the upper respiratory tract and , pulmonary edema and death during long exposure

Check Your Progress 2

Note : a) Write your answer in about 50 words.

b) Check your progress with possible answer given at the end of the unit.

2. What is "sick building syndrome"?

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3. What is the difference between primary and secondary air pollutants?

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4. What are the sources of VOCs?

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5. Give two sources each of the indoor and outdoor air pollutants.

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2.4.4 Urban and Rural Air Pollution

Urban air pollution is mainly caused by both 'mobile' sources (vehicular) and 'stationary' sources (i.e. biomass). Other sources include exhaust fumes from vehicles, emissions from factories and power generation plants.

Three types of air pollution that affect rural areas are **solid fuels** like coal and biomass for cooking and heating, **outdoor pollution** from urban sources and **secondary pollutants** from the transport of emissions far from their primary.

Do You Know?

Lichens are natural biological indicators of air pollution because of their source of nourishment is air. Gray-green crusty lichens indicate highly polluted air, Orange crusty lichens indicate moderate air pollution and leafy lichens indicate clean air.

We will now learn about the effects of air pollution.

2.5 EFFECTS OF AIR POLLUTION

Primary and secondary pollutants are threat to human health particularly respiratory related ailments. Severe exposure to some of these pollutants will be chronic and life threatening. Some pollutants are carcinogenic too. Dear learner, we are all in one way or the other exposed to a number of particulate and gaseous pollutants with inhaled air. The adverse effects of these pollutants may vary from proximity to the source, nature of wind and weather and concentration. These effects may be additive, synergistic or antagonistic. **Additive** effects are those which occur when the exposure to various pollutants produces an effect equal to the sum of the effects of the pollutants acting alone. **Synergistic** effects are those where the sum of the effects of two or more pollutants is greater than the combined effect. **Antagonistic** effects are those where one pollutant minimizes the effect of another pollutant. These effects are more often synergistic in nature.

Smog is a kind of air pollution which reduces visibility and is composed of tropospheric ozone (O_3); primary particulate matter such as pollen and dust; and secondary particulate matter such as sulphur oxides, volatile organic compounds, nitrogen oxides (NO_x) and ammonia gas. It is of two types: Industrial smog and Photochemical smog depending on the nature of pollutants. Industrial smog generally exists in the urban areas. Smog is

Even though the colour of both appears to be brown haze but the differ in their formation and chemical composition

2.5.1 Industrial Smog

It is also called as **grey** or **black** smog and develops under cold and humid climatic conditions especially in urban areas where industrial sources like heating of reactors, roasting process in the nonferrous heavy metals etc., and power plants run on fossil fuels like coal. These industries emit approximately about 2.5 tons of sulfur per hour. This sulphur immediately reacts with water vapour and the secondary pollutant sulphurdioxide is formed. At high humidity SO_2 is rapidly oxidized to form sulphuric acid and sulphate particles. Sometimes catalytic oxidation of dust particles containing heavy metals and soot in the presence of water droplets in the atmosphere makes the droplets acidic. These create a thick blanket of haze known as **acid smog** or **industrial smog**. It is formed close to the ground. The general reactions of industrial smog are given below.

1) $C + O_2 \rightarrow CO_2$ (carbon dioxide)

2) $S + O_2 \rightarrow SO_2$ (sulfur dioxide)

3) $SO_2 + O_2 \rightarrow So_3 + O$ (sulfur trioxide)

4) $SO_3 + H_2O \rightarrow H_2SO_4$ (sulfuric acid)

5) $H_2SO_4 + NH_3 \rightarrow (NH_4)_2SO_4$ (solid ammonium sulfate)

Let us learn about another type of smog called the photochemical smog.

2.5.2 The Photochemical Smog

The photochemical smog is formed in a series of chemical reactions of secondary pollutants in the atmosphere in the presence of sunlight. Photochemical smog appears mostly in urban areas, which has exhaust from vehicles.

The photochemical smog is formed when the primary pollutants like NOx and hydrocarbons are captured in the lower atmosphere on exposure to UV radiation from the sun. The pollutants in the photochemical smog are ozone (O_3), hydrogen peroxide (H_2O_2), organic peroxides (ROOR'), organic hydroperoxides (ROOH), peroxyacyl nitrates (RCO_3NO_2) PAN . The latter are formed by the irradiation of mixtures of alkanals, ozone and nitrogen dioxide. As seen in the previous unit the concentration of O_3 in lower atmosphere is higher than formed by photolysis of NO_2 alone because chemical conversion of NO to NO_2 is not catalyzed by O_3.

The rate of formation of O_3 is influenced by the concentration of peroxy radical (RO_2.). Peroxy radicals are produced when hydroxy radicals (OH•) and HOx react with hydrocarbons. The hydroxy radicals are produced by photolysis of O_3, carbonyl compounds and nitrous acid. Thus the concentration of O_3 in polluted atmosphere is based on intensity of sunlight, nature of hydrocarbons; NO_2/NO ratios and other pollutants like alkanals and CO.

The general reactions of Photochemical Smog are given below:

1) $NO + VOC \rightarrow NO_2$ (nitrogen dioxide)

2) $NO_2 + UV \rightarrow NO + O$ (nitric oxide & molecular O)

3) $O + O_2 \rightarrow O_3$ (ozone)

4) $NO_2 + VOC \rightarrow PAN$ (peroxyacetyl nitrate)

Net result:

$NO + VOC + O_2 + UV \longrightarrow O_3 + PAN$ + other particulates

We would how learn another effect of air pollution caused by the presence of sulphur and nitrogen oxides in the atmosphere called the acid precipitation.

2.5.3 Acid Precipitation

Acid precipitation means any type of deposition like rain, fog, mist or snow which is more acidic than normal. The pH of rain water in the absence of pollution is approximately 5.6 because of solubility of CO_2 in the air to produce carbonic acid. Acid deposition is the combination of precipitation and dry acidic particle fallout with a pH less than 5.5 which occurs usually in the industrial regions.

The acid precipitation principally contains a mixture of sulfuric acid (H_2SO_4) and nitric acid (HNO_3) in a ratio of two to one. As we have read in the previous sections of this unit and also in the previous unit that burning of fuels generates sulfur and nitrogen oxides into the troposphere either by anthropogenic or natural sources. These oxides are oxidized by hydroxyl radicals to sulfuric acid and nitric acids which immediately dissolve in rain water or adsorb to particulate matter and brought down to earth as acid deposition. If the deposition is wet then we can call it as **acid rain**. Some times acidic particles brought down to earth by the phenomena of dry deposition (acid aerosols) called the **acid fog**.

Acid is any chemical that releases hydrogen ions when dissolved in water. The more acidic substance means the higher the concentration of hydrogen ions in the solution. It is expressed as pH. The pH starts from 0(highly acidic) through 7(neutral) to 14(highly basic).This scale represents the negative logarithm (power of 10)of the hydrogen ion concentration, expressed in grams per liter (g/L).

Acid materials reaching the earth by any of the above processes have significant harmful affects on flora, soil and surface waters and change the pH.

Air pollution affects the human health in various ways. Let us learn in the next subsection.

2.6 EFFECTS OF AIR POLLUTION ON HUMAN HEALTH

Ex:To say that a solution has a pH 1 means the hydrogen ion concentration in the solution is 10-1g/L(0.1g/L)

In general human beings are affected by air pollution. The first effected system of our body is the respiratory system due to the synergistic effects of ozone and NOx causing chronic respiratory and cardiovascular diseases. The air pollutants may also alter major body functions such as exchange of oxygen in the lungs and oxygen transport in the blood. Irritant pollutants may lead to irritation and long term damage to eyes, nose, throat and other wet surfaces of the body and the soluble particles get transferred to the blood. One of the most important particles in the atmosphere is H_2SO_4, which irritates the mucous membranes and leads to bronchial constrictions.

Most of the gaseous pollutants like SO_2, O_3 and NO_2 are pulmonary irritants, and cause congestion, edema and even hemorrhage. Gases like NO, H_2S and CO are asphyxiants. These gases bind the hemoglobin molecules and prevent oxygen transfer within the body. Organic gas pollutants such as acrolein (l-propenal) causes eye irritation.

Living spaces in urban areas are polluted and people suffer from chronic effects. Some of the effects are given in Table 2.4

Table 2.4 : Some pollutants and -their effects on human health

Pollutant	Effect on human health
SO_2	Bronchitis
O_3	Inflammation which leads to lung fibrosis and failure of lungs
CO	Reduces the oxygen carrying capacity of blood and contribute to the heart disease
NO_x	Impairs lung function and affect the immune system
Particulate Matter	Broad spectrum of health ailments, respiratory infections to heart disease.

Let us look into the effects specific to various pollutants.

Carbon Monoxide

Inhaling of high concentrations of carbon monoxide shows adverse effects on human beings. It binds irreversibly to hemoglobin in the blood forming carboxyhaemoglobin thereby reduce the oxygen carrying capacity of the blood. When comparing to oxygen, CO has a greater affinity (200 times greater) for haemoglobin.

The concentration of CO at around 10ppm has primary health effect as reduction in awareness and at around 100ppm, headaches and drowsiness are observed. Unconsciousness and death occurs at 250ppm level. The continuous exposure to low levels of CO may cause nervous disorders and finally causes heart disease. At concentrations in excess (1000ppm) death results from anoxia because of insufficient supply of O_2 to body tissues and brain. The effects of CO on human health at different concentrations are given in Table 2.5

Table 2.5 : The effects of CO on human health at different concentrations

Concentration of CO in ppm	Effect on health
10	Lowered awareness and driving performance
50 – 100	Headaches and drowsiness, changes in driving performance and increased reaction time to visual stimulation
>250	Death

Sulfur Compounds

The most important sulfur compound in the atmosphere is sulfur dioxide. The adverse effects of sulfur dioxide are often associated with particulate pollutants since both have common source of generation like combustion of fossil fuels. Hence high concentration of SO_2 is associated with high concentration of particulate matter forming sulfate aerosols. These aerosols show significant threat to human health than do sulfur dioxide emissions alone. These aerosols are retained in the lungs and cause maximum physiological damage. At elevated concentrations these result in higher mortality from bronchitis and lung cancer. Sulfur dioxide alone causes respiratory tract irritation and breathing difficulty. The effects of SO_2 to human health are given in Table 2.6. Table 2.6: Effect of SO_2 to human health at different concentrations

SO_2 (concentration in ppm)	Health effect
500	Reduction in human sensation
800	Threshold of taste
1400	Threshold of odour
4400	Bronchial constriction
20000	Immediate throat irritation
30000	Immediate eye irritation
50000	Immediate coughing

Oxides of Nitrogen

Nitric oxide is a relatively non toxic and non-irritating gas when compared with NO_2 but it is rapidly oxidized to NO_2, which is toxic in nature. Because of its less solubility in water NO_2 generally diffuses deep into the lung and causes tissue damage. At high concentrations it shows the effects like pulmonary edema. The major health problem created by nitrogen oxides is that they are the origins for the mixture of pollutants which form photochemical smog.

Hydrocarbons

All hydrocarbons are relatively nontoxic in nature at the ambient concentrations but they encounter reactions in the atmosphere with O_2, O_3, NO_x, SO_x and other components to form photochemical smog which is very harmful to human health. At high concentrations HCHO (methanal), acrolein, and peroxyacyl nitrate (PAN) cause reduction in visibility, unpleasant odours and cause skin and eye irritation. Hydrocarbons like polycyclic aromatic hydrocarbons (PAH), benzo (α) pyrene (BaP), are carcinogenic in nature.

Ozone

As per the ambient air quality standards ozone is one of the most toxic pollutant. In polluted ambient environmental conditions ozone causes significant physiological and pathological changes in both animals and human beings. The ambient air quality standard for O_3 is 0.12ppm (235mg/m^3). Some of the adverse effects of ozone on exposure are given below.

- At 0.1- 0.4ppm range of for 1-2 hours significant lung function changes in smokers, adults over 55yrs, asthmatics, or individuals with chronic obstructive lung disease are more responsive to O_3 exposures.
- Above 0.12ppm range symptoms including throat dryness, chest tightness, coughing, pain whilst deep breathing, shortness of breath, lassitude, malaise, headache, nausea and also cause decrease in athletic performance.
- O_3 exposures inhibit the immune system activity.
- At 0.08-0.10ppm concentrations for three hours causes increase in the susceptibility of mice to bacterial infectionProlonged and acute exposure causes death.

Particulate Matter

One of the major air pollutants is particulate matter. Because of its size it exhibits toxic effects like irritation. The concentration of adsorbed substances includes SO_x, polycyclic aromatic hydrocarbons (PAH), and heavy metals such as lead, cadmium, zinc and mercury. Particles less than 2.5µm are called “respirable”; they can enter pulmonary tissue and be deposited there. Particles smaller than 10µm are described as “inhalable particles” and be deposited in the respiratory system. The deposition of these particles shows adverse effects on health. It depends on their level of concentration, pH, solubility and synergistic effects with pollutants such as SO_2. The main health effects are acute bacterial and viral bronchitis, bronchial asthma and pulmonary emphysema.

At Total Suspended Particulate Level (ug/m^3) of 200 TSP, minor reversible changes are observed in the lung function of children. At 250-500 TSP acute bronchitis and at 1000 TSP results in increased mortality are observed.

Lead

Exposure to lead particulates results in lead poisoning and the most affected organs are the blood, the brain, the kidney, the nervous system and the reproductive system. Symptoms of acute lead poisoning are shock, anaemia, nervousness, and irreversible kidney and brain damage. In growing children, lead poisoning affects intelligence, length of concentration and activity. Lead poison has the ability to cross the placenta, hence in a pregnant woman results in high lead levels in the foetus that may lead to mental retardation.

Asbestos

Asbestos is the name given to a number of mineral silicates which are compressed together to form fibrous materials. It cannot be classified under distinct mineral species but applied to various fibrous materials with varied composition and physical properties for commercial purpose. The fibres in asbestos are highly toxic in nature with very long dormancy periods. Once the asbestos fiber is inhaled by an individual it has the potential to cause cancer for the rest of the individual's life.

On the basis of chemical and mineralogical studies asbestos is grouped under silicate mineral. Asbestos is a mixture of six varieties of silicate minerals having common properties of eponymous asbestiform nature. They are chrysotile, crocidolite, amosite, anthophyllite, tremolie and actinolite.

The asbestos particulates show a considerable public health problem due to their wide use in the construction and insulating material. Inhalation of the fibres causes the lung disease known as **asbestosis** which is characterized by chronic inflammation and scarring disease affecting the tissue of the lungs. Patients with asbestosis may experience acute shortness of breath and are at an increased risk for certain cancers, including lung cancer and, less commonly, mesothelioma (cancer of the lining of the body cavity).

Chromium

Chromium emissions in the air are mainly from industries like iron and chrome, and associated industries like refining, chemical and refractory processing, cement production plants, automobiles, leather tanneries, chrome based dyes and stainless steel production.

The harmful effects of chromium are related to respiratory ailments like shortness of breath, coughing, and wheezing. Chronic exposure results in septum damage, disrupted pulmonary function- pneumonia and lung cancer.

Let us now learn how the air pollution affects building and materials.

2.7 EFFECTS OF AIR POLLUTANTS ON BUILDINGS AND MATERIALS

In fact, most of the materials are affected by the direct exposure of air pollutants. Some of them are different types of stones, metals, papers and textiles which may be deteriorated by either of the processes of abrasion, chemical exposure, deposition and corrosion. The moisture, temperature and freezing and thawing are the conditions which influence the rate of deterioration.

1. **Abrasion**: Solid particles of sufficient size travelling at high speed can cause destructive abrasion.
2. **Deposition and Removal**: Solid pollutants deposited on the surface may cause discoloration and the removal of the deposit causes deterioration to the structure.

Moisture is required to cause the corrosion of iron and steel in the presence of sulfur oxides. Metal samples in dry air containing oxides of sulfur do not corrode. Deterioration by a chemical reaction will increase with temperature. Surface which is below the dew point temperature will cause surface condensation and enhanced reaction with soluble pollutant gases. If temperatures drops below the freezing point of water, freezing and defrosting cause cracks and spalling on stone, exposing new surfaces to reactive pollutants.

3. **Direct and Indirect Chemical Attack**: Some of the air pollutants like sulfur oxides, mainly sulfur trioxide (SO_3) react with marble or limestone ($CaCO_3$) irreversibly and converted to gypsum that cause deterioration. Materials made by leather absorb sulfur dioxide (SO_2) which gets converted to sulphuric acid that damage the leather goods.

4. **Corrosion:** Gases like sulfur dioxide (SO_2) and sulfur trioxide (SO_3) are corrosive in nature and in the presence of moisture they undergo electrochemical reaction and corrode the metal objects.

We will now learn how the buildings and materials may get affected in terms of discoloration, loss of material, soiling and structural failure.

Stone: In general most of the historic monuments are constructed by different types of stones. For example: Marble, Granite and Mosaic. These get affected in the following manner in the case of marble.

Marble: Marble is a metamorphic rock of carbonate mineral. The constructions made by marble or alternate calcareous stones are vulnerable to air pollutants like total suspended particulate matter (TSPM), oxides of sulphur and nitrogen. We have already learnt about acid rain and how SO_2 gets converted into H_2SO_4.This sulphuric acid goes deep into the marble stone thereby solubilises the calcium carbonate and drags to the surface by the process of natural heating and reaction with moisture, where it is deposited as gypsum. During wet and dry environment cycles recurring deposition of gypsum and the porous crust formed has no link to the stone. It can easily detatch the stone and scale it off. The dust particles in TSPM contain soot which quickly gets deposit on porous crust which appears as a black surface.

Decolouration of Taj Mahal- a 17th Century Islamic Architecture: A Case Study

India's most famous pride and tourist attraction Taj Mahal is not an exception to be a non-living victim of the pollution. The industries like Mathura oil refinery, rubber processing, automobile located around Agra have been responsible for producing pollutants like sulphur dioxide and nitrogen oxides. These air pollutants react with water vapor present in the atmosphere forms sulphuric and nitric acid. These acids reach the ground with rain in the form of acid rain. Acid rains decolorize the white marble and also corrode the marble which is known as "**Marble cancer**".

Check Your Progress 3

5. Match the words in column A with those of column B appropriately in the following:

1.	Industrial smog	a.	Asbestos
2.	SO_2	b.	Lung fibrosis
3.	Acid rain	c.	H_2SO_4, $(NH_4)_2SO_4$
4.	Photochemical Smog	d.	Carcinogenic
5.	O_3	e.	H_2SO_4, HNO_3
6.	PAH	f.	Bronchitis
7.	Asbestos	g.	O_3

2.8 KEY WORDS

Acid Precipitation : Includes acid rain, acid fog, acid snow, and any other form of precipitation that is more acidic than normal (i.e. less than pH 5.6). Excess acidity is derived from certain air pollutants; namely, sulphur dioxide and oxides of nitrogen.

Asbestos Fibres : Crystals of asbestos, a natural mineral, that have the form of minute strands; asbestos is a serious health hazard in indoor spaces.

Greenhouse Effect : An increase in the atmospheric temperature caused by increasing amounts of carbon dioxide and certain other gases that absorb and trap heat, which normally radiates away from Earth.

Hydroxy Radical : The hydroxyl group (OH), missing the electron. The hydroxyl radical is a natural cleansing agent of the atmosphere. It is highly reactive, readily oxidizes many pollutants upon contact, and thus contributes to their removal from the air.

Nitrogen Oxides (NOx) : A group of nitrogen-oxygen compounds formed when some of the nitrogen gas in air combines with oxygen during high-temperature combustion. Nitrogen oxides are a major category of air pollutants and, along with hydrocarbons, are a primary factor in the production of ozone and other photochemical oxidants that are the most harmful components of photochemical smog. Nitrogen oxides also contribute to acid precipitation.

Photochemical Smog : The brownish haze that frequently forms on otherwise clear, sunny days over large cities with significant amounts of automobile traffic. Photochemical smog results largely from sunlight-driven chemical reactions among nitrogen oxides and hydrocarbons, both of which come primarily from auto exhausts.

Primary Pollutants : Pollutants released directly into the atmosphere mainly as a result of burning fuels and wastes, as opposed to secondary pollutants.

Secondary Air Pollutants : Air pollutants resulting from reactions of primary air pollutants resident in the atmosphere. Secondary air pollutants include ozone, other reactive organic compounds, and sulphuric and nitric acids.

2.9 LET US SUM UP

There are a number of forms of air pollutants which exists in the form of gases, fumes, clouds, smoke, mist, fog, smog, haze, dust, aerosols, etc. They are classified as natural/anthropogenic, primary/secondary, particulates/gases, ambient air/indoor air/ global, stationary/mobile etc. Air pollutant concentrations are measured in the form of their threshold values which are different for different pollutants. Above these values the pollutants shows adverse effects on human beings. The common problem is the respiratory tract infection, bronchitis and other diseases can occur due to inhalation of toxic pollutants. Pollutants such as arsenic, lead, fluoride, insecticides and pesticides affect human beings adversely. Air pollutants also deteriorate the objects made of ferrous, aluminum, copper, silver, building materials, leather, paper and textile.

2.10 REFERENCES AND SUGGESTED FURTHER READINGS

1. Fundamentals of Environmental Chemistry by A.K.De
2. Environmental Chemistry by Stanley Manahan
3. Textbook of Environmental Science by Pearson.

2.11 ANSWERS TO CHECK YOUR PROGRESS

Answers to check your progress should include the following points.

1 a. **Lead**: Exhaust of the vehicles which use leaded petrol, waste incinerators, processing of ore and metals and aircraft operating on leaded aviation fuel, utilities, lead-acid battery manufacturers, lead smelters, lead-based paint, ceramics, pipes, plumbing materials, solders, gasoline, batteries, ammunition, and cosmetics.

b. **Nitrogen dioxide**: It is produced by photochemical reactions of O_3, peroxy radical (RO_2), OH•, HO_2, and H_2O_2

c. **Carbon dioxide**: It is generated by the combustion of organic matter weathering, or biological decomposition.

2. In poorly ventilated dwellings pollutants will accumulate to higher concentrations than that of outside causes irritations of eyes, nose, and throat, dry mucous membranes and skin erythema known as 'Sick building syndrome'.

3. Primary pollutants are the pollutants which are released directly in to the atmosphere from a particular source of pollution which means they are the direct products of evaporation and combustion. Where as the primary pollutants which can under go further reactions by light energy, heat or the presence of other chemicals converted in to undesirable toxic compounds are known as secondary pollutants.

4. VOC's emitted from paints, and other solvents, wood preservatives, aerosol sprays, cleansers and disinfectants, moth repellents and air fresheners, stored fuels and automotive products, dry - cleaned clothing, pesticides,

building materials, furnishings, office equipment such as copiers and printers, graphics and craft materials including glues and adhesives, permanent markers and photographic solutions.

5. 1. c
   2. f,
   3. e
   4. g
   5. b
   6. d
   7. a