

## 6.

# Noise Pollution

**Syllabus:** Syllabus: Noise Pollution- Sources, effects, standards, and control.

Sound is a physical disturbance in a medium such as a gas, liquid or solid which can be detected by a human ear. It may also be defined as “**a sensation excited by a physical disturbance in a medium caused by the vibrations in its molecules. Sound is propagated as a pressure wave**”. As a matter of fact, sound is a pure tone, hormonally related, having fixed frequencies and amplitudes, occurring at a regular intervals and produces meaningful communication and pleasure in hearing sound travels through the air or any other medium in the form of longitudinal waves. The vibration of the surrounding source produces these waves. The velocity of sound in air is 0.33 km per second.

The word “noise” comes from the Latin word *nausea* meaning “seasickness”, or from a derivative (perhaps Latin *noxia*) of Latin *noceō* = “I do harm”, referring originally to nuisance noise. Noise is often defined as “**unwanted unpleasant sound**”. Noise pollution may be defined as unwanted sound release into the atmosphere without any concern to the adverse effect it may have. In other words “**Unwanted and unpleasant sound dumped in to the atmosphere leading to pain in the ear and causing health hazards is called noise pollution**”. It is a physical form of pollution and has no persistent effects but it has direct effect on recipients. Noise level in many urban-industrial complexes are found to be detrimental to human health. They have adverse effect on the sense organs, cardiovascular, glandular and nervous systems.

### **Duration and Frequency of Sound**

Quantitatively the duration of sound can be defined in time, the frequency of sound in Hertz/Cycles per second(cps) and the intensity of sound(=volume) in decibels(db). The frequency of sound is represented by the number of pressure variations per second. Based on frequency, the sound can be pure tone, broad band noise or white noise. Pure tone is a noise consisting of a single sound wave. Broad band noise is a noise consisting of frequencies randomly distributed throughout the audible range. Of the many sounds in the environment, we only hear the sounds whose frequencies fall in the range 20Hz to 20,000Hz. These frequencies are termed as **sonic frequencies**. The sounds below 20Hz are sub-sonic sounds. Our ears are most sensitive for basic speech frequencies(i.e., ordinary conversation) that is 500Hz to 2000Hz. Animals like dogs and bats can hear much beyond 20,000Hz, the frequencies known as **ultrasonic frequencies**.

### **Measurement of Noise**

Intensity of sound and noise is measured by a sound meter and is expressed in a unit called the decibel (dB). Decibel is  $1/10^{\text{th}}$  of unit bel. The name bell is given after the name of Alexander Graham Bel. Intensity of sound is a pressure of energy flow per unit area.

Decible is a ratio expressed as a logarithmic scale to a reference sound level.

$$\text{bel} = \log_{10} I/I_0$$

decibel =  $10 \log_{10} I/I_0$   
 where  $I$  = Sound intensity  
 $I_0$  = Reference level

Decibel (dB) can also be used as a measure of sound pressure level (SPL). In such case dB is defined as -

$$\text{SPL or dB} = 10 \log \frac{P^2}{P_0^2}$$

Where  $P$  = Root mean square value of pressure variation  
 $P_0$  = Reference pressure =  $2 \times 10^{-5} \text{ N/m}^2$

The intensity of sound in normal conversation is about 60 decibels. While 65 dB is the noise level for hearing a conversation at a distance of one meter, 125 dB gives the sensation of pain in the ear and 150 dB may kill a human being.

1 dB is equivalent to the faintest sound that can be just heard by human ear. In terms of sound pressure, one decibel is equivalent to a sound pressure of 0.0002 micro bars (dynes per  $\text{cm}^2$  = an energy of about  $10^{-16}$  watts). In terms of intensity, the range of human hearing is from 0 to more than 120 dB.

Table 6.1 : Some representative values of sound levels

| S.N. | Sound effect                         | Sound level (In dB) |
|------|--------------------------------------|---------------------|
| 1.   | Threshold of normal hearing          | 0 (Theoretical)     |
| 2.   | Normal conversations                 | 50-60               |
| 3.   | Speech interference                  | 75                  |
| 4.   | Annoyance/Irritation                 | 80                  |
| 5.   | Disturbance in motor activity of man | 90                  |
| 6.   | Physiological disturbance in man     | 120                 |

### Loudness

Loudness is the function of both frequency and intensity of sound. Unit of loudness is 'sone'. One sone is equal to the loudness of 40 dB sound pressure at 1000 cpm. 50 sones and above is very uncomfortable for man within his range of hearing while 10-50 sones (= 85 dB) depending upon frequency, can cause ear damage. In general, people begin to complain when in residential areas, unwanted noise levels reach 35 to 40 dB and begin to threaten the community action when it reaches 50 dB.

### SOURCES OF NOISE POLLUTION

The sources of noise pollution are categorized into two groups -natural sources and anthropogenic sources.

#### A. Natural Sources

It includes lightning, thunderstorm, and explosions due to volcanic eruptions, sound due to earthquakes, and sound of wild animals. The sound produced from the natural sources might be short termed and hence their effect may also be short.

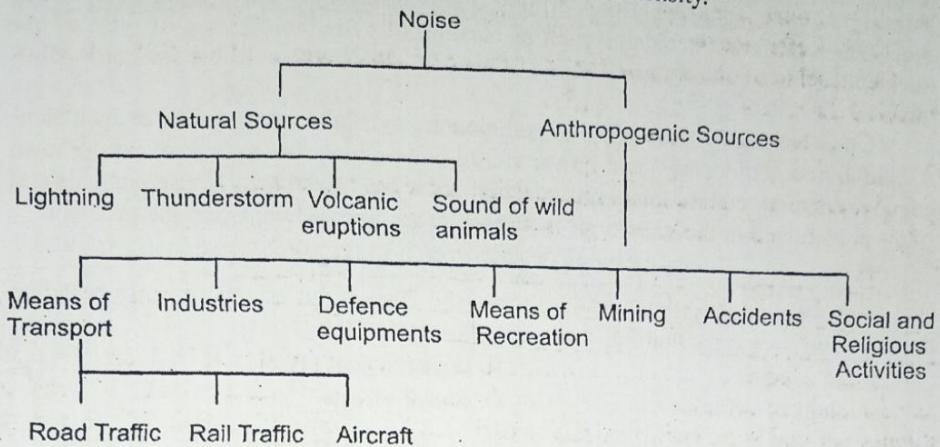
#### B. Anthropogenic Sources

The anthropogenic sources of noise pollution are of following types-

##### 1. Means of Transport : This can be subdivided into-

(a). Road Traffic: Vehicles on roads produce for people more than any other source. It includes two wheelers, buses minibuses, car, taxi, trucks and other means of road transport.

**(b). Rail Traffic:** The noise of this source is generally of lower frequency than that of street vehicles. It produces a noise of about 100-decibel intensity.



**(c). Aircraft :** the engines of aircraft high intensity sounds that are really injurious. There are peak noise levels when aircrafts fly overhead or take off and land (150-decibel) at airports the noise being produced from aircraft engines.

Table 6.2. The noise emitted by various sources.

| S.No. | Source of Noise                               | Intensity of Noise (in dB) |
|-------|---|----------------------------|
| 1.    | House noise<br>(without use of any appliance) | 30-40 dB                   |
| 2.    | Road noise<br>(without horns and sirens)      | 70 dB                      |
| 3.    | Heavy traffic on highways                     | 70-90 dB                   |
| 4.    | Scooter                                       | 80 dB                      |
| 5.    | Vacume cleaner                                | 80 dB                      |
| 6.    | Bus/Truck                                     | 90 dB                      |
| 7.    | Loud speakers                                 | 83 dB                      |
| 8.    | Rock music                                    | 100 dB                     |
| 9.    | Motor car horn                                | 120 dB                     |
| 10.   | Jet air crafts                                | 110-150 dB                 |
| 11.   | Sirens of 50 HP                               | 150 dB                     |
| 12.   | Space rockets                                 | 180 db                     |

2. **Industries:** Industries such as textile mills, printing-press, engineering establishments, etc. The number of industries is increasing due to industrialization.
3. **Means of Recreation:** It includes radio, tape recorder, television, cinema, video, orchestra, pop songs, drums, musical instruments, loud speakers, etc. These produce sound that irritates diaphragm of our ears.
4. **Social and Religious Activities:** In our country loud speakers and other sound systems are used in during various religious occasions like Durga puja, Ramlila, and social activities, which causes noise pollution. Use of fireworks during Deepawali and Dashehra like festivals and during the occasion of wedding are also responsible for intense and unpleasant sound.
5. **Defense Equipments:** Defence equipments such as tanks, artillery and rocket launching explosions, practise firing, etc. and vehicles. The use of defense equipments such as

- guns, bombs, machine guns, missiles, tanks also produce intense sound.
6. **Mining:** Mining includes blasting, drilling, dumping, crushing and cleaning equipments.
7. **Accidents:** Different accidents such as blasting of cylinder, blasting of tyres of vehicles, burning of armory and shops of fireworks also are responsible for noise pollution.

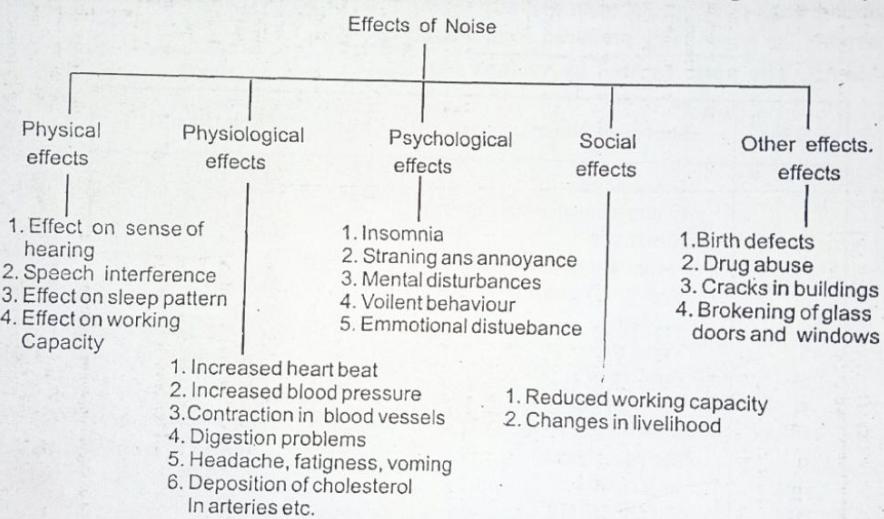
Other common source of noise pollution are dynamite blasting, use of Jack hammers, pile drivers, bulldozers, lawn mover etc. In our country, due to lack of proper town planning residential, commercial and industrial areas are mixed-up. House, schools and hospitals are situated in the vicinity of industries. It has further intensified the problem.

#### EFFECTS OF NOISE POLLUTION

Noise pollution harms ourselves variously. The various effects of noise pollution on human beings are classified into four categories-

- A. Physical effects.
- B. Physiological effects.
- C. Psychological effects.
- D. Social effects.
- E. Other effects.

- A. Physical Effects :** Noise pollution affects us physically in many ways-
- (a). **Effects on Sense of Hearing:** Noise can affect the sense of hearing in three ways-



1. The physical manifestation of noise pollution is the effect of hearing ability. long term exposure to noise may result in temporary or permanent shifting of the hearing threshold of a person depending upon the level and duration of exposure.
2. The immediate and acute effect of noise pollution is impairment of hearing (*i.e. total deafness*). The effect of noise on audition is well recognized. Mechanics, locomotive drivers, telephone operators etc. All have their hearing. Impairment as a result of noise at the place of work. Physicist, physicians & psychologists are of the view that continued exposure to noise level above 80 to 100 db is unsafe. Loud noise causes temporary or permanent deafness.
3. Long term exposure may permanently damage sensory cells, delicate tympanic membrane or ear drum. Noise pollution affects ears in two ways- temporary damage and permanent damage.

The noise having intensity more than 90 decibels causes damage to ear. The level

**TABLE 3.10. Comparision between photochemical and classical smog**

| <b>Photochemical Smog</b>  | <b>Classical Smog</b>  |
|--|--|
| <p>1. It is a mixture of reactants and products that result from the interaction between volatile organic compounds and oxidants.</p> <p>2. It is called as oxidizing smog.</p> <p>The first noticed incidence of photochemical smog was in Los Angeles in USA thus it is referred as Los Angles smog.</p> <p>The main components of photochemical smog are:</p> <ul style="list-style-type: none"> <li>(i) hydrocarbon</li> <li>(ii) NOx</li> <li>(iii) Sunlight</li> </ul> <p>Sources for the formation are gasoline and combustion.</p> | <p>1. Coal induced smog is formed by the interaction of <math>\text{SO}_2</math>, smoke and water to form sulphuric acid mist.</p> <p>2. Chemically reducing with high levels of <math>\text{SO}_2</math> and it is called reducing smog.</p> <p>3. The first noticed incidence of classical smog, was in London so it is also termed as London smog.</p> <p>4. The main component of London smog were:</p> <ul style="list-style-type: none"> <li>(i) SOX</li> <li>(ii) Particulates</li> <li>(iii) Humidity or water</li> </ul> <p>5. Sources are mainly coal.</p> |

### 3.7 GREEN HOUSE EFFECT

Greenhouse means a building made mainly of glass, with heat and humidity regulated for growing plants. The atmosphere acts like a glass in a green house.

Atmosphere absorbs some of the long wave radiation emitted by earth and radiates the energy back to the earth thus temperature of the earth is maintained.

The atmosphere surrounding the earth in this manner plays a very important role in maintaining an even temperature on the surface of earth.

"A greenhouse is that body which allows the short wavelength incoming solar radiation to come in, but does not allow the long wave outgoing terrestrial infra red radiation to escape".

The Greenhouse effect may therefore be defined "as the progressive warming up of the surface of earth due to blanketing effect of manmade  $\text{CO}_2$  in the atmosphere".

The four major greenhouse gases, which cause adverse effects, are

1. Carbon dioxide ( $\text{CO}_2$ )
2. methane ( $\text{CH}_4$ )
3. Nitrous oxide ( $\text{N}_2\text{O}$ ) and
4. Chlorofluorocarbons (CFCs)

Among these  $\text{CO}_2$  is the most common and important greenhouse gas. Ozone and  $\text{SO}_2$  also act as serious pollutants in causing global warming. The other greenhouse gases such as methane and chlorofluorocarbons contribute about 18% and 14% respectively to the global warming.

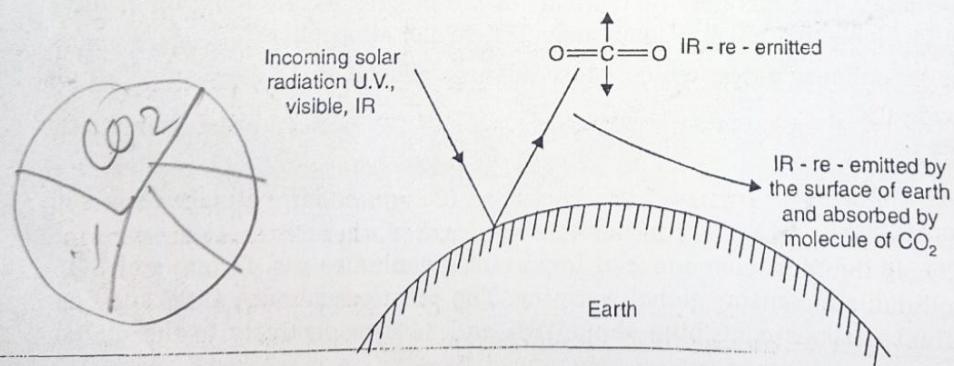
The pollutants generated by different anthropogenic activities are increasing the global atmospheric concentration of certain heat trapping gases, which act similar to a blanket, trapping heat close to the surface that would otherwise escape through the atmosphere to the outer space. This process is known as **greenhouse effect**, because it reminds some observers of the heat trapping effect of the glass walls in a horticultural green house. Human activities are changing the composition as well as behaviors of the atmosphere at an unprecedented rate.

**TABLE 3.11. Major Sources of Green House Gases Composition**

| S.N. | Gases                              | Percentage composition | Major Sources   |
|------|------------------------------------|------------------------|---|
| 1.   | Carbon dioxide ( $\text{CO}_2$ )   | 52%                    | Combination of fossil fuel, deforestation, respiration. |
| 2.   | Methane $\text{CH}_4$              | 19%                    | Anaerobic decomposition of organic waste.               |
| 3.   | Nitrous oxide $\text{N}_2\text{O}$ | 4%                     | Fertilizer, combustion of fossil fuel.                  |
| 4.   | Ozone $\text{O}_3$                 | 8%                     | Photochemical reaction in troposphere.                  |
| 5.   | Chloro fluoro carbon CFC's         | 14%                    | Refrigerant, manufacturing foams.                       |
| 6.   | Miscellaneous                      | 1%                     | —   |

### Formation of Green House Effect

The temperature of the earth's surface is maintained by the energy balance of the sun rays that strike the planet and the heat that is radiated back into the outer space under normal concentration of carbon dioxide in atmosphere. But, when concentration of  $\text{CO}_2$  in the atmosphere increases, the thick envelop of this gas prevents the heat from being re-radiated out. The heated earth can re-radiate this energy as the radiation of longer wavelength. Concentrated layer of  $\text{CO}_2$  will act as the glass panels of a green house, allowing the sun rays to filter through but preventing the heat from being escaping in the outer space. Thus the warming the troposphere of the atmosphere.



**Fig. 3.12** Green house effect, I.R. radiation absorbed by  $\text{CO}_2$  molecules is re-emitted

Consequently greenhouse effect is a phenomenon which is based on the principle of infrared absorption characteristics of gases. More the concentration of  $\text{CO}_2$  greater will be the absorption of thermal radiations which mean that more infra red radiation is trapped and re-emitted back to earth's surface resulting in a heat trap increasing mean global temperature.

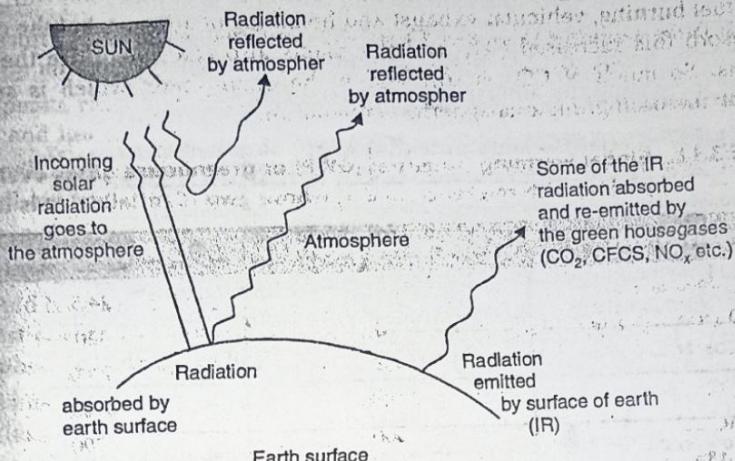


Fig. 3.13 Representation of global warming

#### 3.7.1 Major Sources of Greenhouse Gases

A number of industrial as well as agricultural operations generate and emit waste gases into the atmosphere.

Some of the important sources of greenhouse gases are:

1. **Industrial operation:** A number of factories spread all over the world burn immense quantity of coal, oil and natural gases and emit enormous amount of  $\text{CO}_2$ , together with another undesirable gases through their chimneys into the atmosphere.
2. **Power Stations** based of fossil-fuels are significant and wide spread major sources of manmade  $\text{CO}_2$ .
3. A large fleet of automobiles, railways, air craft etc, use an immense quantity of diesel and petrol releasing huge amount of  $\text{CO}_2$  every year.
4. **Burning of fire woods and deforestation** are the major sources for the production of  $\text{CO}_2$ . According to an estimate deforestation has added 90 to 180 billion tonnes of carbon to be atmosphere.
5. An estimate indicates that plants, soils and earth, which are the large storage pools of unoxidized carbon, contain about 2 trillion tonnes of carbon. These trees release carbon as  $\text{CO}_2$  after oxidizing it.
6. A large scale forest fire either kindled by deliberate or inadvertent actions of man, contributes much to the release of  $\text{CO}_2$ , favouring green-house effect.
7. The **reduction in forest cover** due to industrial expansion and urbanization etc. has increased the concentration of  $\text{CO}_2$  in the air.

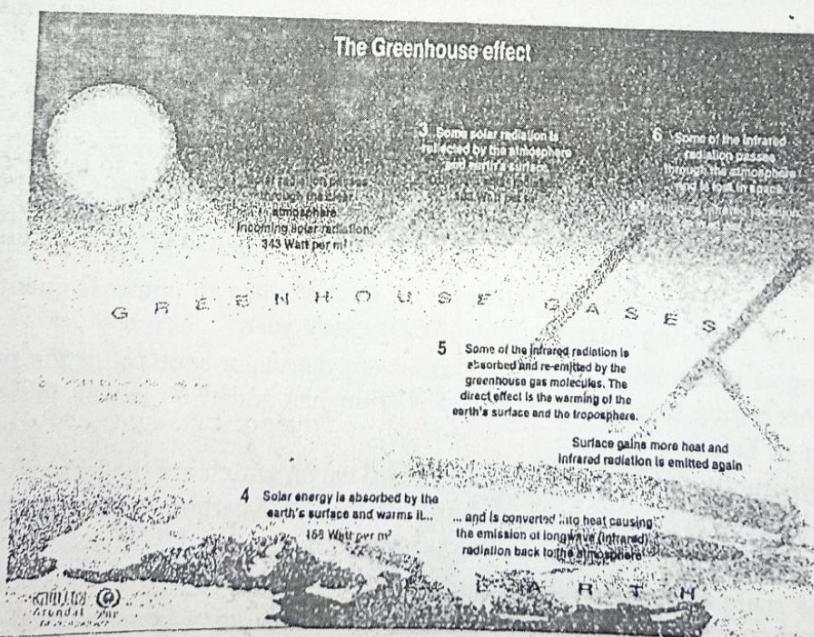
8. **Halogenated gases (CFCs etc.)** and **gadons** are released to the atmosphere during the operations and maintenance of appliances and equipments using these molecules as coolants and propellants. These gases drastically affect the climatic changes.

A huge amount of  $\text{CO}_2$  gets introduced into the environment from furnaces of power plants, fossil fuel burning, vehicular exhaust and breathing of animals, but the oceans may not be able to absorb this increased  $\text{CO}_2$ , and the plants also can not utilize the whole during photosynthesis. So much of  $\text{CO}_2$  is still left in the atmosphere, which is supposed to be responsible for increasing the atmospheric temperature.

**TABLE 3.12. Global warming potential (GWP) of greenhouse gases over a 100 year period, with reference to  $\text{CO}_2$  whose gwp (Capital) value is taken as one**

| Greenhouse Gas                       | GWP (1992 Report) | GWP (1994 Report) |
|--------------------------------------|-------------------|-------------------|
| $\text{CH}_4$ (Methane)              | 11                | 24.5              |
| $\text{N}_2\text{O}$ (Nitrous oxide) | 270               | 320               |
| CFC-11                               | 3400              | 4000              |
| CFC-12                               | 7100              | 8500              |
| HCHC-22                              | 1600              | 1700              |
| HFC-13a                              | 1200              | 1300              |

It is observed that in addition to  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$  CFC-11 and CFC-12, hydrofluorocarbons. Perfluorocarbons and sulphur hexafluoride have also been found to be responsible for global warming.



**Fig. 3.14 The Greenhouse effect**

## 7.2 Greenhouse Effect and Climate Change

The greenhouse effect will bring about the following important changes in the climate of the earth:

1. As a result of rise in temperature of the earth due to greenhouse effect the oceans get warm up and sea level would rise flooding low lying regions.
2. In temperate regions, the winter will be shorter and warmer and the summer will be longer and hotter. A warmer climate is likely to make some cities extremely hot.
3. There will be enormous increase in rain fall but the problems of desertification, drought and soil erosion will further worsen.
4. The tropics may become wetter and the subtropics, which are already dry, are expected to become drier.
5. The rapid increase in industrialization and urbanisation, coupled with drastic decrease in forest cover, will create a layer of impenetrable gases on the surface of the earth atmosphere covering the planet earth into a hot blast furnace.
6. The plants and animals will also be affected resulting in the disruption of the whole ecosystem.

The most obvious effect of climate change will be on agriculture. Because CO<sub>2</sub> is a natural fertilizer the plants will grow larger and faster with increasing CO<sub>2</sub> in the atmosphere.

7. At first sight, the abnormally fast growth of plants might be expected to be beneficial because the yields of major crops might increase, but with the increase in the yield, the soils may become impoverished or poor more rapidly. The bigger plants with larger yield may cause many complicated problems such as :

  - (1) Disruption of natural eco system.
  - (2) Increase in yield means lower prices to farmers.
  - (3) Plants will be less rich in nitrogen and hence they are likely to be susceptible to pests.
  - (4) Soil will become poor or impoverished rapidly. As a result it will become incapable for yielding good plant growth.

## Consequences of Greenhouse Effect or Global Warming

1. The best clues to the ongoing global warming can be had from the world's glaciers. Ice is melting at an alarming rate in the Alpine regions causing concerns for nations like Australia, Switzerland, and France. It has been observed that one half of the ice cover has disappeared over the last century.
2. According to climatologists from the University of Delaware (USA), a rise in temperature by 2–4°C will lead to a two fold increase in the number of hot days during summer.
3. Global warming is changing our planet at a much faster and unpredictable rate. It has resulted in 20–25% more storms, 10% more vegetation and early onset of spring in the northern hemisphere.

4. Due to Industrial revolution, atmospheric CO<sub>2</sub> levels have risen from 280 ppm to 362 ppm contributing significantly to **global warming**.
5. Natural fires in China may be responsible for speeding up of the rate of **global warming**. Natural fires in the coal fields of Northern China could account for as 3% of worldwide CO<sub>2</sub> emissions, a major greenhouse gas.
6. Global warming has also been found to effect nesting cycles of the birds.
7. Rising temperatures are reducing sea ice in the Arctic, endangering polar bears, seals and fish. The Western Arctic is one of the fastest warming regions in the world, warming at a rate of 0.75°C per decade for the past three decades.
8. In a separate statement, WWF called on governments to pledge their commitments to curbing global warming because the temperature increase across the globe has resulted in an increased incidence of heart and respiratory disorders.
9. The **global warming** is altering the habits, migration and breeding of animals and this could eventually affect humans. Already Costa Rican forest birds are migrating to cooler areas.
10. A study by the World Wide Fund for Nature (WWF) has documented how several species of plants, birds, and other wildlife were adapting to the global warming of the earth's atmosphere. The only option to protect animals is to adopt strict restrictions on the emission of greenhouse gases, which are responsible for the gradual increase in the temperature of the planet.
11. Global emissions of greenhouse gases may create serious threat to **coral reefs** in worldover. Increasing levels of CO<sub>2</sub> are reducing the ability of coral animals to make the limestone skeletons that build reefs.
12. High pressure CO<sub>2</sub> pumped from deep within the Earth may cause **earthquakes**.

#### Control and Remedial Measures of Greenhouse Effect

The greenhouse effect can be controlled by taking the following important measures.

1. Reducing the consumption of fossil fuels such as coal and petroleum. This can be achieved by depending more on non conventional renewable sources of energy such as wind, solar, nuclear and bio gas energies.
2. Disposing of the green house gases as they are formed elsewhere them in the atmosphere.
3. Recovering green house gases present already in the atmosphere and disposing off them elsewhere.
4. Learn to adapt and accept the changing climate.
5. International co-operation for attempting the reduction of green house gases.

#### 3.8 CREATION AND DEPLETION OF OZONE LAYER

Ozone is present at all altitudes in the atmosphere, mainly in the **stratosphere** extending from 16 kms 40 kms. This upper layer of the atmosphere enveloped by ozone (16 km – 40 km) is

commonly termed as ozonosphere, ozone layer, stratospheric ozone layer, protective layer or ozone umbrella. Composition of air in the stratosphere remains fairly uniform throughout the region. On the other hand, ozone concentration differs by about 10 ppm in the **stratosphere** compared to 0.05 ppm in the **troposphere**. This increase in concentration of ozone has a profound beneficial effect on plants, animals and human beings of the biosphere.

This presence of ozone layer in the stratosphere is of vital significance for all biota, because the harmful ultra violet rays, which are lethal to life on the earth are not allowed to enter the earth's atmosphere by **ozone layer or ozone umbrella**. In the absence of this layer, all the ultra violet rays of the sun will reach the earth's surface and consequently the temperature of the lower atmosphere will rise to such an extent that the **biological furnace** of the biosphere will turn into a **blast furnace**. Thus the ozone layer strongly absorbs or blocks the short wave ionising ultra violet rays and so protects the life on earth from severe radiation damage.

### Formation of Ozone

In stratosphere, ozone is produced from the oxygen and it is also broken down by natural forces. It is thus constantly created and destroyed maintaining an optimum concentration for effective filtration of the excess UV radiation reaching the earth.

The thickness of ozone layer has been found to be comparatively low in Polar Regions because of cold climate conditions and other factors.

Ozone is also formed at ground level (troposphere) in a very little concentration of about 0.05 ppm. In large pollutants generated by anthropogenic process such as oxides of nitrogen and other noxious gases react with ultraviolet radiations and these gases result in the formation of ozone, which acts as a harmful pollutant for plants and animals including man. Ozone at ground surface is also responsible for the formation of potentially more hazardous pollutant known as **smog** through a serious of photochemical reactions involving oxides of nitrogen hydrocarbons and other primary pollutants.



The thickness of ozone layer is measured in Dobson Units (DU), where 1 DU = 0.01 mm of the compressed gas at 0°C and 760 mm Hg pressure.

### Depletion of Ozone Layer

Ozone hole was first noticed in 1979 in Antarctica (South Pole). In 1985–86, the US scientists confirmed that ozone layer was depleted definitely by CFCs.

The depletion of ozone layer has been found to be much more acute on polar regions particularly Antarctica (South Pole) than in other parts of the earth. This may be due to two important reasons.

1. Prevailing cold climate conditions and other complex atmospheric parameters including air turbulence.
2. Absence of nitrous oxide ( $\text{N}_2\text{O}$ ) in these areas,  $\text{N}_2\text{O}$  present under normal conditions in atmosphere destroys  $\text{ClO}$  and checks ozone-depletion, while in polar regions,  $\text{N}_2\text{O}$  at sub-zero temperature freezes into ice droplets or clouds, leaving  $\text{ClO}$  free to decompose ozone molecules.  $\text{ClO}$  in turn accumulates and continues to destroy ozone.

The most alarming situation is that ozone layer was totally destroyed between the altitudes of 13.5 and 19 km creating ozone hole of 5.5 km thick. The surface area of the hole has been estimated to be about 23 million sq. km, which is twice the size of Antarctica land mass. Ozone hole in Antarctica is generally very prominent between the months of later August to early October because of prevalence of very stable cold situation in upper reaches of atmosphere of Antarctica. The cold situation helps in prolonging the ozone depletion process.

In India, ozone levels have been found to be lowest during November and December and highest in summer. Across the country, the thickness of ozone layer has been found is given in table

**TABLE 3.13. Thickness of ozone layer in some cities of India**

| S.NO. | Name of city in India | Thickness of ozone layer (in DU) |
|-------|-----------------------|----------------------------------|
| 1     | Kudaikanal            | 240-180 DU                       |
| 2     | New Delhi             | between 270-320 DU               |
| 3     | Srinagar              | between 290 - 360 DU             |

### Mechanism of Ozone Depletion

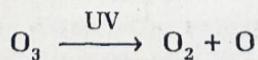
It includes,

- (1) The Natural Process (2) The Anthropogenic Process.

#### *(1) The Natural Process*

Atmosphere oxygen absorbs ultraviolet radiation shorter than 240 nm and photodissociates into two oxygen atoms. These combine with other  $O_2$  molecules to form ozone. During the process surplus energy of nascent  $O_3$  is often transferred to the nearby molecules as kinetic energy which slightly raises the surrounding atmospheric temperature.

Ozone too is effective in absorbing particular short wavelength UV radiation in the range 210–293 nm, releasing atomic oxygen. This natural mechanism cannot disturb the ozone equilibrium because the loss of ozone caused by natural process is compensated by the creation of ozone through atmospheric circulation. Since the fate of these atoms is similar to those which were photodissociated, i.e., the transfer of kinetic energy, union with molecular oxygen and interestingly the release of fresh ozone.

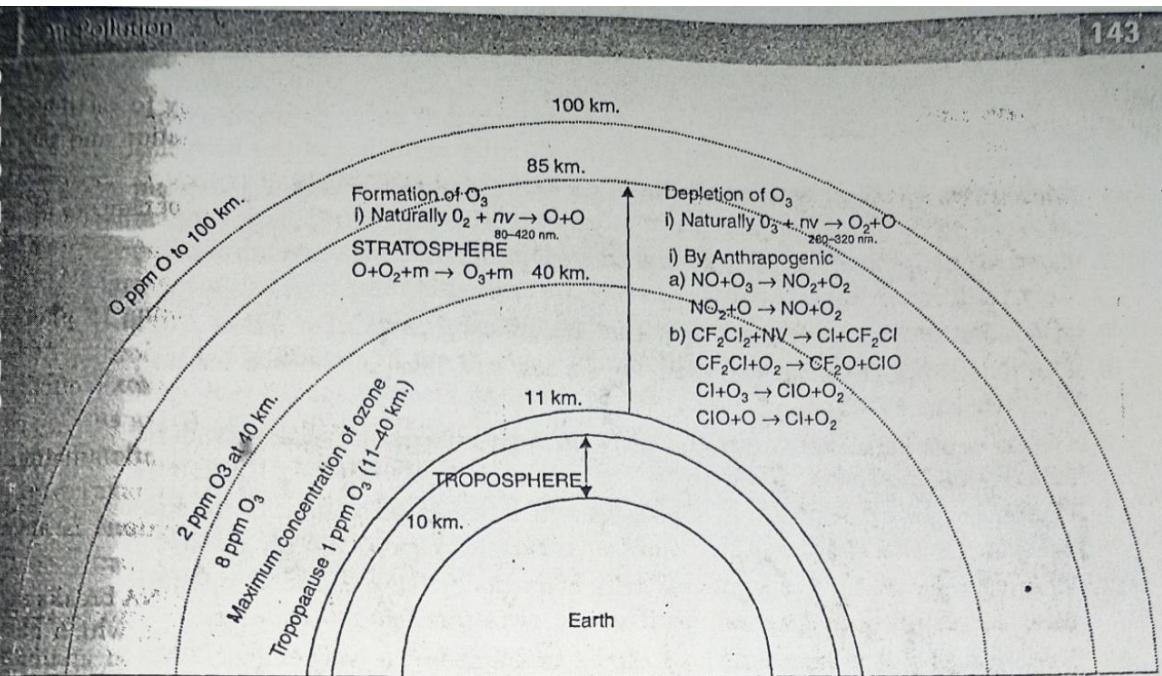


#### *(2) The Anthropogenic Process*

Anthropogenic activities generated different types of pollutants in troposphere especially oxides of nitrogen and CFCs which deplete the concentration of stratospheric ozone. Mechanism of ozone depletion by anthropogenic process may be given by following three hypothesis-

##### **(1) Nitrogen Oxide Hypothesis—Anthropogenic activities**

Play a significant role in the matter of  $NO_x$  load to the stratosphere affecting ozone concentrations. The supersonic air crafts (SST) fly at ozonospheric cruising altitudes because



**Fig. 3.19** Concentration of ozone in different level and chemical reaction involved in formation and depletion of ozone in stratosphere.

### Effects of Ozone Depletion

It is universally accepted that the ozone layer in the stratosphere protects us from the harmful UV radiations coming from sun. Ozone accounts for only three parts in ten millions of Earth's atmosphere, but plays several crucial roles in the radiation balance of the planet.

The depletion of this ozone layer by modern man's industrial activities have imparted serious implications by letting "Ozone-eaters".

### Effect of Depletion of Ozone on Man

- With the depletion in atmospheric ozone there is danger of the increase in the flux of ultraviolet radiation over earth's biosphere. The range of wavelengths particularly affected by the changes in atmospheric ozone is from 2900 Å or 3200 Å. All the known effects of these radiations are harmful for man's life.
- UV radiation—the narrow spectral band which is thought to cause most biological damage—appears to trigger two quite distinct immunological effects. One is confined to patches of skin that are actually irradiated, while the other develops in the immune system as a whole.
- The three kinds of skin cancer—basal cell carcinoma, squamous cell carcinoma and melanoma are rapidly climbing the list of human diseases caused by UV rays.
- Langerhans cells in the epidermis of human skin are players in immune surveillance.
- UV radiations cause blood vessels near the skin's surface to carry more blood, making the skin hot, swollen or red, causing sun burns.

6. Curiously melanoma is caused by intermittently exposing of the body to relatively high doses of UV radiations and is often associated with burning sensation and skin aging.
7. Long exposure to UV radiation caused by O<sub>3</sub> depletion creates handful of cancers that defy traditional links between poverty and diseases.
8. UV radiation causes leukemia and breast cancer.
9. UV radiations are also absorbed by cornea and lens in the eye leading to photo keratitis and cataracts.
10. Ozone at ground level enters the body through inhalation and exerts its toxic effects directly on the lungs.
11. Ozone at low concentration is also known to cause accumulation of inflammatory cells at the site of lung injury causing severe damage to the lung.
12. The capacity of lung phagocytes which normally fight bacterial infections is also affected resulting in increasing incidence of respiratory infections.
13. Exposure of ozone has been shown to be associated with lung cancer, DNA breakage, inhibition and alteration of its replication and formation of DNA adduct, which has been implicated in premature aging and finally cell death.
14. Ozone exposure has also been implicated in dizziness and visual impairment - a sign of central nervous system damage, enlargement of spleen and thymus and impairment of the immune system.
15. Photochemical smog is the major cause of ozone exposure causing urban air pollution posing a threat to human health.
16. Ozone, in highly populated areas occurs with concentration ranging from 0.04 ppm to 0.7 ppm in air, while in upper atmosphere its concentration is more than 1.0 ppm. So the crew and passengers of flying commercial air crafts often suffer adverse reaction from ozone present in unfiltered air cabin.
17. Any increased concentration of ozone brings about changes in the nucleic acids, DNA and RNA. So increased UV absorption will have drastic results.
18. Ozone has been reported to be a strong irritant and is supposed to reach the lungs and respiratory tract much faster than the oxides of sulphur. Even its concentration causes pulmonary edema.

#### **Effects of Ozone Depletion on Plants**

1. Exposure to air containing ozone results in the lesions to plants usually confined to the upper surfaces of leaves. These lesions are characterized by the uniformly distributed white or brown flecks and stippling in irregularly distributed blotches.
2. Ozone flecking is observed with the plants of grape, citrus and tobacco. At 0.02 ppm it damages tomato, pea, pine and other plants. In pine seedlings it causes tip burn.
3. Plant proteins are also susceptible to UV injury, because they absorb strongly around 280 nm. 20-25% chlorophyll reduction and harmful mutation have also been observed.
4. In USA and California fruits and vegetable yields have reduced due to ozone pollution.

5. Ozone alongwith, other pollutants like  $\text{SO}_2$  and  $\text{NO}_x$  are affecting the growth of crop especially spinach, potato, clover and alfalfa etc.
6. In plants  $\text{O}_3$  enters through stomata. It causes visible damage to leaves, thereby reducing their photosynthetic activity. It thus decreases the yield of certain food crops and changes the effectiveness of agricultural chemicals.  $\text{O}_3$  reduction thus damages the food production.
7. Due to ozone reduction, intense UV radiation causes evaporation of surface water through the stomata of the leaves and decreases the soil moisture content. Thus,  $\text{O}_3$  in the atmosphere protects us but it is lethal when it comes in direct contact with us and plants at earth's surface.
8. Ozone reacts with many fibres, such as cotton, nylon and polyester, dyes etc. The extent of damage appears to be affected by light and humidity.
9. Available informations suggest that ozone is the most toxic photochemical product causing injury to plants.

#### *Effects of ozone-depletion on climate*

Scientists believe that ozone-reduction in troposphere may drastically change the weather elements like temperature, wind pattern, acid rains and precipitations etc.

By absorbing UV radiations the ozone layer heats the atmosphere. The added heating up of the surrounding stratosphere causes a temperature inversion between 15 and 50 km. altitude from  $-56^{\circ}\text{C}$  to  $-2^{\circ}\text{C}$ . This defines the stratosphere as having a temperature gradient, while tropospheric temperature increases steadily. Today industrial operations are increasing the amount of trapped radiation leading to rapid rise in global temperature by letting ozoneeaters such as CFCs,  $\text{NO}_x$  and  $\text{SO}_2$  etc.

Every molecule of either of two common CFCs— $\text{CCl}_3\text{F}$  (called as CFC-11) and  $\text{CCl}_2\text{F}_2$  (as CFC-12) has the same global warming effect as 10,000 carbons dioxide molecules. Ozone depletion changes spectral composition of solar electromagnetic radiations. The increased solar UV radiation causes green house effect changing the global energy and radiation balance.

#### *Green House Effect Responsible for Arctic Ozone Hole*

Accumulation of greenhouse gases in the atmosphere can even create an Arctic ozone hole. The accumulation of these gases in the troposphere traps the heat radiated by the earth's surface. Even the warm air rising from the troposphere loses buoyancy at the lower portion of the stratosphere, because the ozone in this region can absorb solar heat directly making the temperature similar to that of the upward air. Thus warm air cannot reach the upper part of the stratosphere.

The ozone hole threat to the Arctic is because of the fact that the temperatures are dropping. In this way it can reach the same temperature as the Antarctic stratospheric cloud (about  $-80^{\circ}\text{C}$ ), where the ozone depleting substances destroy the ozone.

No body is quite sure why the mesosphere is cooling at such a faster rate. There are different explanations such as the planetary waves, which are huge atmospheric waves created by weather systems in the troposphere. It may believe that the cooling of the mesosphere is an ominous sign of the major changes that are to come in global climate.

## 7.2 DEFINITION

The word noise is derived from the latin "nausea" meaning a feeling of sickness at the stomach with an urge to vomit.

**Noise is defined in number of ways:**

1. Noise is a sound without value.
2. Noise is an unwanted, unpleasant or disagreeable sound that causes discomfort.
3. Noise is a wrong sound in a wrong place at the wrong time.

## 7.3 NOISE POLLUTION

**Noise Pollution** is any unwanted electromagnetic signal that produces a displeasing effect and which interferes with human communication comfort and health.

**Noise pollution** refers to sounds in the environment that are caused by humans and that threaten the health or welfare of human or animal inhabitants.

So **noise pollution** is the unwanted sound dumped into the environment without regard to the adverse effect it may have.

### 7.3.1 Sources and Causes of Noise Pollution

Poor urban planning may give rise to noise pollution, since side-by-side industrial and residential buildings can result in noise pollution in the residential area.

The prevailing source of artificial noise pollution is from transportation. In rural areas, train and airplane noise can disturb wildlife habits, thereby affecting the manner in which animals in areas around train tracks and airports hunt and mate.

In urban areas, automobile, motorcycle, and even entertainment noise can cause sleep disruption in humans and animals, hearing loss, heart disease (as a result of stress), and in severe cases even mental instability.

The sources of noise are more in urban and industrial areas than in rural areas. The sources in general may be stationary or mobile.

#### 1. Stationary Sources

Use of loudspeakers on various occasions like festivals, elections, worships in temples, mosques and during advertisements, mining operations, use of bulldozers, drillers and dynamites to break rocks, household gadgets like vacuum cleaner, TV, radio, stereo, grinder, mixer etc., common vegetable and fish markets.

#### 2. Mobile Sources

Road traffic, railway traffic, air traffic, navigation etc the sources of noise can be classified in following categories:

The mobile source of most outdoor noise worldwide is mainly construction and transportation systems, including:

1. Transportation or Traffic Noise
2. Constructional Noise.
3. Industrial Noise
4. Noise in building.
5. Noise from consumer product.

#### 1. Transportation or Traffic Noise

- (a) **Road Traffic Noise:** In the city, the main sources of traffic noise are the motors and exhaust system of autos, smaller trucks, buses, and motorcycles. This type of noise can be increased by narrow streets and tall buildings, which produce a canyon in which traffic noise reverberates.
- (b) **Air Craft Noise:** Today the problem of low flying military aircraft has added a new dimension to community annoyance, as the nation seeks to improve its nap-of-the-earth aircraft operations over national parks, wilderness areas and other areas previously unaffected by aircraft noise has claimed national attention over recent years.
- (c) **Noise from railroads:** The noise from locomotive engines, horns and whistles, and switching and shunting operation in rail yards can impact neighboring communities and railroad workers. For example, rail car retarders can produce a high frequency, high level screech that can reach peak levels of 120 dB at a distance of 100 feet, which translates to levels as high as 138, or 140 dB at the railroad worker's ear.

#### 2. Construction Noise

The noise from the construction of highways, city streets, and buildings is a major contributor to the urban scene. Construction noise sources include pneumatic hammers, air compressors, bulldozers, loaders, dump trucks (and their back-up signals), and pavement breakers.

#### 3. Noise in Industry

Although industrial noise is one of the less prevalent community noise problems, neighbors of noisy manufacturing plants can be disturbed by sources such as fans, motors, and compressors mounted on the outside of buildings. Interior noise can also be transmitted to the community through open windows and doors, and even through building walls. These interior noise sources have significant impacts on industrial workers, among whom noise-induced hearing loss is unfortunately common.

#### 4. Noise in Building

Apartment dwellers are often annoyed by noise in their homes, especially when the building is not well designed and constructed. In this case, internal building noise from plumbing, boilers, generators, air conditioners, and fans, can be audible and annoying. Improperly insulated walls and ceilings can reveal the sound of amplified music, voices, footfalls and noisy activities from neighboring units. External noise from emergency vehicles, traffic, refuse collection, and other city noises can be a problem for urban residents, especially when windows are open or insufficiently glazed.

### 5. Noise from Consumer Products

Certain household equipment, such as vacuum cleaners and some kitchen appliances have been and continue to be noisemakers, although their contribution to the daily noise dose is usually not very large.

#### 7.3.2 Measurement of Noise—Unit of Sound

The two important properties of sound are sound intensity and sound frequency. The unit of measurement of intensity is decibel (db). It is ratio expressed as logarithmic scale relative to a reference sound pressure level. Decibel scale begins with zero. Human ear is sensitive to sound waves in the frequency range of 20 Hz to 20 KHz. Human ear is generally sensitive to middle frequencies of about 100 Hz. The acceptable noise level for a building is the maximum level of noise which causes no damage to acoustics of a building.

$$\text{Sound Intensity Level} = 10 \log \frac{\text{Intensity measured (I)}}{\text{Reference Intensity (I}_0\text{)}} \\ \text{dB} = 10 \log \frac{I}{I_0}$$

**Noise level:** Noise level is usually expressed in terms of Sound Pressure Level in dB.

$$\text{Sound Pressure Level (SPL)} = 20 \log \frac{P}{P_0}$$

Where P is Pressure variation measured ( $\text{N/m}^2$ )

And  $P_0$  is Standard reference pressure  $2 \times 10^{-5} \text{ N/m}^2$

**Noise level of various source of sound:** The table below gives the noise level of various sources of sound.

**TABLE 7.1: Noise level of various source of sound**

| Source of sound                | Sound level in decibel (dB) |
|--------------------------------|-----------------------------|
| 1. Threshold of hearing        | Zero                        |
| 2. Normal breathing            | 20                          |
| 3. Whispering sound            | 30                          |
| 4. Conversation between people | 40                          |
| 5. Normal conversation         | 50                          |
| 6. A small shop                | 60                          |
| 7. Traffic on a busy road      | 70                          |
| 8. Small-scale industry        | 80                          |
| 9. Large scale industry        | 90                          |

**Noise Permissible limits and Ambient Standard:** Different industries are also the source of noise pollution. Some permissible noise exposure for industrial workers, Limits for automobiles at source as well as for domestic appliances are given in tables on next page.

**TABLE 7.2: Permissible noise exposure for industrial workers**

| S. No. | Exposure time (in hours/day) | Limit in db (A) |
|--------|------------------------------|-----------------|
| 1      | 8                            | 90              |
| 2      | 4                            | 93              |
| 3      | 2                            | 96              |
| 4      | 1                            | 99              |
| 5      | 1/2                          | 102             |
| 6      | 1/8                          | 108             |
| 7      | 1/16                         | 111             |
| 8      | 1/32                         | 114             |

**TABLE 7.3: Noise limits for automobiles at manufacturing stage**

| S. No. | Categories of automobiles                       | Unit in db (A) |
|--------|---|----------------|
| 1.     | Motorcycles, scooters and three wheelers        | 80             |
| 2.     | Passenger cars                                  | 82             |
| 3.     | Commercial vehicles of up to 4MT                | 85             |
| 4.     | Commercial vehicles of above 4MT and up to 12MT | 89             |
| 5.     | Above 12MT                                      | 91             |

**TABLE 7.4: Noise limits for domestic appliances**

| S. No. | Domestic appliance                        | Limits in (db) sound pressure levelat one meter distance from the operator |
|--------|---|--|
| 1.     | Window air conditionerof 1 ton to 1.5 ton | 68   |
| 2.     | Air coolers                               | 60   |
| 3.     | Refrigerators                             | 46   |

**TABLE 7.5: Ambient noise standards**

| S. No. | Area             | Day time | Noises (A) night time |
|--------|------------------|----------|-----------------------|
| 1.     | Industrial area  | 75       | 70                    |
| 2.     | Commercial area  | 65       | 55                    |
| 3.     | Residential area | 55       | 45                    |
| 4.     | Silence zone     | 50       | 40                    |

### 7.3.3 Effects of Noise Pollution

Noise has become a very important "stress factor" in the environment of man. It has many effects on exposed population. It can have a number of undesirable effects depending upon its intensity, frequency, duration and time of the day when it occurs.

Frequency of sound is denoted by Hertz (Hz). Human ear can hear frequencies between 20 to 20,000 Hz. Effect of noise on human health depends on:

- (i) Quality
- (ii) Duration
- (iii) Sensitivity of the individual.

The noise pollution produces the following three main effects:

#### A. Psychological Effect

Noise leads to emotional disturbances, however, are difficult to measure. Irritating noise at work place reduces concentration efficiency and working capacity.

#### B. Masking Effect

Masking noise prevents the ear from registering other important sounds and signals. These effects change the balance in predator/prey detection, by disturbing and interfering the sounds of communications especially during reproduction time period and loss of hearing.

#### C. Physiological Effect

The various effects of noise pollution on human beings are classified as auditory effects (directly affecting ear and hearing ability) and non-auditory effects (affecting other physiological process). Similarly, noise can show various detrimental effects on other living organisms like plants and animals.

##### (a) Auditory

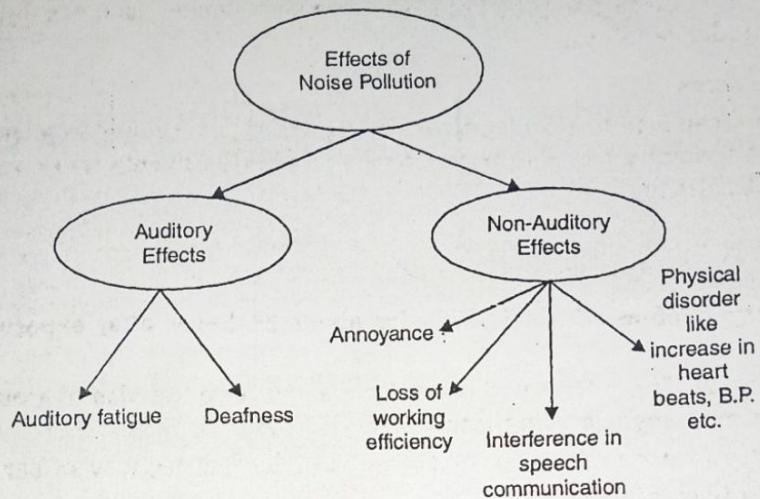
- Auditory fatigue (when level of noise ranges from 85-90 db)
  - Deafness (repeated exposure to noise level > 90 db)
- The most acute and immediate effect of noise pollution is impairing of hearing which may cause auditory fatigue and may even finally lead to deafness.
- Auditory fatigue occurs when exposed to noise levels of 90 dB or above. In metro cities, most of the shopkeepers, cobblers, fruit sellers complain tinnitus in ear.
  - Deafness occurs when exposed to loud noise. The workers working in the noisy workplace environment may suffer from Noise Induced Hearing Loss (NIHL). Hearing loss may be temporary or permanent. Prolonged exposure to high noise levels leads to permanent deafness.

##### (b) Non auditory

- Annoyance (listens dislike the noise content).
- Efficiency (noise pollution decreases efficiency of working).
- General changes in body (high blood pressure, fatigue, hypertension, tetanus).

Non-auditory effects are also alarming, because of the fact that they also cause severe diseases. It includes interference with speech communication, annoyance leading to ill-temper,

mental disturbance and violent behavior. It also causes loss of working efficiency due to physiological disorder. Physiological disorders associated with noise include increase heart rate, increase in blood pressure, and change in skin temperature and blood circulation, Cardio-vascular diseases, and change in levels of hormones. In females, the chances of miscarriage and congenital birth defects are more in noisy environment.



**Fig. 7.1** Auditory and Non auditory effects of noise pollution

#### **Noise Pollution Effects on Humans**

Effect of noise pollution on human health is a matter of great concern. The reason being the adverse consequences that high noise levels have on human health. Noise pollution can affect human in several ways, some of which are listed below:

##### **1. Hearing Problems**

Exposure to noise can damage one of the most vital organs of the body, the ear. Hearing impairment due to noise pollution can either be temporary or permanent.

- When the sound level crosses the 70 dB mark, it becomes noise for the ear.
- Noise levels above 80 decibels produce damaging effects to the ear.
- When ear is exposed to extreme loud noise (above 100 decibels) for a considerable period of time, it can cause irreparable damage and lead to permanent hearing loss.

##### **2. Cardiovascular Issues**

A noisy environment can be a source of heart related problems. High intensity sound can cause a dramatic rise in blood pressure as noise levels constrict the arteries, disrupting the blood flow. The heart rate (the number of heart beats per minute) also increase. These sudden abnormal changes in the blood increase the likelihood of cardiovascular diseases in the long run.

##### **3. Sleep Disturbances**

Noise pollution also cause detrimental effect on the overall well-being of any human. Noise causes disturbance to a good night's sleep, and when this occurs, the person feels extremely

annoyed and uncomfortable. People deprived of uninterrupted sleep show a sharp dip in their energy levels which often results into extreme fatigue. This can considerably decrease a person's ability to work efficiently.

#### 4. Interference in Verbal Communication

A noisy environment that produces more than 50–60 decibels simply does not allow 2 people to communicate properly. Interpreting the speech of a second person becomes quite difficult and may lead to misunderstandings.

#### 5. Mental Health Problems

Exposure to loud sound can lead to elevated stress levels as well as stimulate violent behavior. A constant noise in the vicinity can also trigger headaches, make people tense and anxious, and disturb emotional balance.

#### 6. Effects on the Ear

##### (a) Deafness

- (i) **Temporary Deafness:** This persists for about 24 hours after exposure to loud noise.
- (ii) **Permanent Deafness:** Repeated or continuous exposure to noise of around 100 dB results in permanent hearing loss.  
Even single exposure to noise of 160 dB can lead to rupture of ear drum and permanent deafness.  
In cases of long term exposure to moderately loud noise, the onset and progress of noise induced deafness is very gradual and by the time the individual is already somewhat deaf, he/she may not be aware of the deafness until the deafness starts affecting the person's ability to hear normal conversation, telephone rings and doorbells etc.

(b) **Auditory Fatigue:** Noise of 90 dB causes buzzing and whistling in the ears.

#### 7. Effects on other systems

- (a) **Decreased Work Efficiency:** With increasing noise, efficiency of work decreases because of disturbed concentration, annoyance and early onset of fatigue.
- (b) **Increased Intracranial Pressure:** (Fluid Pressure of the Cerebrum Spinal Fluid, the fluid present inside the cavities of brain and between brain and skull). This leads to Headache, Nausea and Giddiness.
- (c) **Increased Blood Pressure:** Noise can very effectively raise the Blood Pressure of even a normal person.
- (d) **Increased Heart Rate, Respiration rate and Sweating:** Diminished Night Vision, Colour Perception and visual disturbances.

#### 8. It decreases the efficiency of a man

Regarding the impact of noise on human efficiency there are number of experiments which point out the fact that human efficiency increases with noise reduction. Thus human efficiency is related with noise.

**9. Lack of concentration**

For better quality of work there should be concentration. Noise causes lack of concentration. In big cities, mostly all the offices are on main road. The noise of traffic or the loud speakers of different types of horns divert the attention of the people working in offices.

**10. Fatigue**

Because of Noise Pollution, people cannot concentrate on their work. Thus they have to give their more time for completing the work and they feel tiring.

**11. Abortion is caused**

There should be cool and calm atmosphere during the pregnancy. Unpleasant sounds make a lady of annoy in nature. Sudden Noise causes abortion in females.

**12. It causes blood pressure**

Noise Pollution causes certain diseases in human. It attacks on the person's peace of mind. The noises are recognized as major contributing factors in accelerating the already existing tensions of modern living. These tensions result in certain disease like blood pressure or mental illness etc.

***Effect of Noise on Vegetation*****Poor quality of crops**

Now is well known to all that plants are similar to human being. They are also as sensitive as man. There should be cool and peaceful environment for their better growth. Noise pollution causes poor quality of crops in a pleasant atmosphere.

***Effect of Noise on Property***

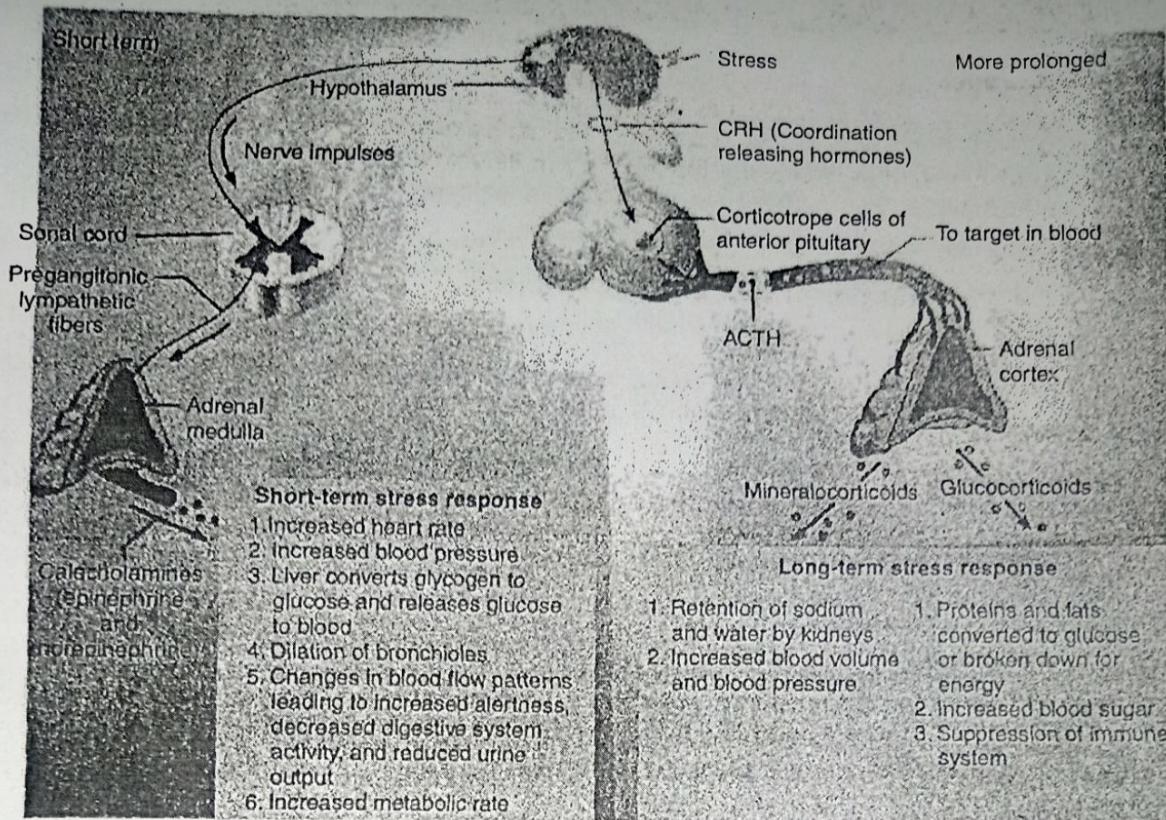
Loud noise is very dangerous to buildings, bridges and monuments. It creates waves which struck the walls and put the building in danger condition. It weakens the edifice of buildings.

***Noise Pollution Effects on Animals***

Man-made noise pollution has made the Earth an uncomfortable place to stay for animals as well. Hearing loss and rapid increase in heart rate are some of the ill-effects of noise pollution on animals. High intensity sound induces fear, forcing them to abandon their habitat. Noise pollution damages the nervous system of animal. Animal loses the control of its mind. They become dangerous.

**Effects of noise on animals is given below:**

1. Anxious behavior in animals is commonly observed in the form of trembling when they are exposed to high decibel levels. Intolerable noise levels can decrease a cow's capacity of milk production. These animals require a calm and relaxed environment to provide a better milk yield.
2. Research has proven that aircraft induced noise is responsible for a significant decrease in reproduction activity in a wide range of animals. Noise pollution effects can also be seen on chicken in the form of a sharp drop in egg production. Stunted growth in chickens due to intense noise has also been observed.
3. Underwater animals such as whales and dolphins too experience discomfort due to noise pollution caused by submarines, shipping and companies.



**Fig. 7.2** Short term and long term response due to noise pollution

4. Birds in urban areas, that use their sharp hearing abilities to hunt prey, are at loss due to intervention of man-made noise. High noise levels can also negatively affect the breeding and feeding patterns of some animals. This is one of the reasons why certain species have become extinct.
5. Sea animals produce varying sound levels among each other. However, the noise of commercial ships does not allow these animals to communicate properly, which can wreak havoc on their reproductive function. Sonar navy tests can hurt the whale's ear and reduce its ability to breed and feed.

#### 7.3.4 Control Techniques of Noise Pollution

Noise pollution needs to be controlled so that acceptable levels of noise pollution can be maintained.

##### (1) Control at Receiver's End

Ear protection aids like ear-plugs, ear-muffs, noise helmets, headphones etc. must be provided to reduce occupational exposure.

**(2) Control of Noise at Source**

The working methods are improved by:

- (a) Designing, fabricating and using quieter machines to replace the noisy ones.
- (b) Proper lubrication and better maintenance of machines.
- (c) Installing noisy machines in sound proof chambers.
- (d) Covering noise-producing machine parts with sound-absorbing materials to check noise pollution.

**(3) Acoustic Zoning**

Increased distance between source and receiver by zoning of industrial noisy areas, bus terminals and railway stations etc. away from residential areas would go a long way in minimizing noise pollution.

**(4) Sound Insulation at Construction Stages**

- Sound travels through the cracks that get left between the door and the wall. To reduce noise this space should be packed.
- Sound insulation can be done by constructing windows with double or triple panes of glasses.
- Acoustical tiles, hair felt, perforated plywood etc. can be fixed on walls to reduce noise.

**(5) Planting of Trees**

Green plants and shrubs along roadside, hospitals, educational institutions etc. help in reducing noise

**(6) Town Planning**

A rational town planning can reduce outdoor noise pollution. The city or town can be divided into suitable zones and residential zones in places away from workshop, main roads, railways, factories etc.

**(7) Use of Silencer**

Noise pollution can be controlled by making use of sound absorption silencers. Usually glass wool or mineral wool covered with a sheet of perforated metal for mechanical protection is suitable.

**(8) Vibration Damping**

A layer of damping material in the form of resilient pad made of rubber, neoprene, cork or plastic may be used for reducing vibrations coming out from a vibrating machine.

### 7.3.5 Steps to Control Noise Pollution

#### 1. The First Approach has been to Reduce Noise at Aource

Design and fabrication of silencing devices and their use in aircraft engines, trucks, cars, motorcycles, industrial machines and home appliances would be an effective measure. Protection to workers can be provided through wearing devices such as earplugs and earmuffs.

#### 2. Making a Change in Design and Operation

Noise pollution may be control by making a change in design and operation of machines, vibration control, sound proof cabins and sound-absorbing materials etc.

#### 3. By Adopting Permissible Limits

It can get reduced by prescribing noise limits for vehicular traffic, ban on honking of horns in certain areas and planning main traffic arteries, industrial establishments, amusement areas, residential colonies, creation of silent zones near schools and hospitals and resigning of building to make them noise proof. Other measures can involve reduction of traffic density in residential areas giving preferences to mass public transport system.

**TABLE 7.6: Acceptable noise levels**

| S. No. | Location                            | Acceptable noise levels (in decibel) |
|--------|-------------------------------------|--------------------------------------|
| 1.     | Recording studios of T.V. and radio | 25 to 30                             |
| 2.     | Auditorium                          | 35 to 40                             |
| 3.     | Libraries and hospitals             | 40 to 45                             |
| 4.     | Schools                             | 45 to 50                             |
| 5.     | Residential buildings               | 45 to 50                             |
| 6.     | Banks, big offices                  | 50 to 60                             |
| 7.     | Factories                           | 60 to 65                             |
| 8.     | Normal conversation                 | 45 to 50                             |
| 9.     | Household                           | 40                                   |
| 10.    | Light vehicles                      | 65 to 105                            |
| 11.    | Heavy vehicles                      | 85 to 100                            |

#### 4. Control of Indoor Noise

➤ Where outdoor noise levels have been high, the following methods can be applied for reducing their effect.

Locate in the building as far as possible from noise source. The noise level drops about 6dB each time the distance is doubled.

### 4.9 DRINKING WATER STANDERED OF SOME COUNTRIES

Drinking water quality standards have been issued by various authorities like WHO (World Health Organization), ISI (Indian Standard Institution), EPA (Environmental Protection Agency). Drinking water quality standard recommended by some authorities are given in table below.

TABLE 4.17: Water Quality Parameters and Drinking Water Standard

| Sl.<br>No. | Parameters                             | Units<br>(IS: 10500-1991) | Drinking Water  |               |
|------------|--|---------------------------|-----------------|---------------|
|            |  |                           | Desirable       | Maximum       |
| 1          | Colour                                 | Hazen units               | 5               | 25            |
| 2          | Odour                                  | -                         | Unobjectionable | -             |
| 3          | Taste                                  | -                         | Agreeable       | -             |
| 4          | Turbidity                              | NTU                       | 5               | 10            |
| 5          | pH value                               | -                         | 6.5 to 8.5      | No relaxation |
| 6          | Total hardness (as CaCO <sub>3</sub> ) | mg/l                      | 300             | 600           |
| 7          | Iron                                   | mg/l                      | 0.3             | 1             |
| 8          | Chlorides                              | mg/l                      | 250             | 1000          |
| 9          | Residual, free Chlorine                | mg/l                      | 0.2             | -             |
| 10         | Dissolved Solids                       | mg/l                      | 500             | 2000          |
| 11         | Calcium                                | mg/l                      | 75              | 200           |
| 12         | Copper                                 | mg/l                      | 0.05            | 1.5           |
| 13         | Manganese                              | mg/l                      | 0.1             | 0.3           |
| 14         | Sulphate                               | mg/l                      | 200             | 400           |
| 15         | Nitrate                                | mg/l                      | 50              | No relaxation |
| 16         | Fluoride                               | mg/l                      | 1               | 1.5           |
| 17         | Phenolic compounds                     | mg/l                      | 0.001           | 0.002         |
| 18         | Mercury                                | mg/l                      | 0.001           | No relaxation |
| 19         | Cadmium                                | mg/l                      | 0.01            | No relaxation |
| 20         | Selenium                               | mg/l                      | 0.01            | No relaxation |
| 21         | Arsenic                                | mg/l                      | 0.05            | No relaxation |
| 22         | Cyanide                                | mg/l                      | 0.05            | No relaxation |

|    |  |              |        |               |
|----|--|--------------|--------|---------------|
| 23 | Lead   | mg/l         | 0.05   | No relaxation |
| 24 | Zinc   | mg/l         | 5      | 15            |
| 25 | Anionic detergents   | mg/l         | 0.2    | 1             |
| 26 | Chromium   | mg/l         | 0.05   | No relaxation |
| 27 | Polynuclear aromatic Hydrocarbons                                | mg/l         | -      | -             |
| 28 | Mineral oil  | mg/l         | 0.01   | 0.03          |
| 29 | Pesticides   | mg/l         | Absent | 0.001         |
| 30 | Radioactive materials<br>(a) Alpha emitters<br>(b) Beta emitters | Bq/l<br>Bq/l | -<br>- | 0.1<br>0.037  |
| 31 | Alkalinity   | mg/l         | 200    | 600           |
| 32 | Aluminlum  | mg/l         | 0.03   | 0.2           |
| 33 | Boron  | mg/l         | 1      | 5             |

TABLE 4.18: Drinking Water quality Standard Recommended by Various Authorities

| Physical and Chemical Standard      | EPA (US) | WHO GL         | CPHEO | Australian GL |
|-------------------------------------|----------|----------------|-------|---------------|
| Turbidity                           | -        | -              | 1     | 5             |
| pH                                  | 6.5-8.5  | -              | 7-8.5 | 6.5-8.5       |
| TDS                                 | -        | Less than 1000 | 500   | 500           |
| Chloride as Cl ppm                  | 250      | 250            | 200   | 250           |
| Sulphate as $\text{SO}_4^{2-}$ mg/L | 250      | 500            | 200   | 250           |
| Fluoride as F mg/L                  | 2        | 1.5            | 1     | 1.5           |
| Nitrate as $\text{NO}_3^{2-}$ mg/L  | -        | -              | 45    | 100           |
| Calcium as Ca mg/L                  | -        | -              | 75    | -             |
| Magnesium as Mg mg/L                | -        | -              | 30    | -             |
| Iron as Fe mg/L                     | 0.3      | -              | 0.1   | 0.3           |
| Manganese as Mn mg/L                | 0.05     | 0.5            | 0.1   | 0.05          |
| Copper as Cu mg/L                   | 1        | 2              | 0.05  | 2             |
| Mineral oils mg/L                   | -        | -              | 0.01  | -             |

## Nephelometry and Turbidimetry

### 15.1 Introductory

Nephelometry and turbidimetry are techniques of analysis that are closely allied to colorimetry. Much of the theory and equipment used in colorimetry apply with little modification to both these techniques.

Both nephelometry and turbidimetry are based on the scattering of light by non-transparent particles suspended in a solution. However, the two techniques differ only in the manner of measuring the scattered radiation.

When light is allowed to pass through a suspension, the part of the incident radiant energy is dissipated by absorption, reflection, and refraction while the remainder is transmitted. Measurement of the intensity of the transmitted light as a function of the concentration of the suspended particles forms the basis of turbidimetric analysis. This is illustrated in Fig. 15.1.

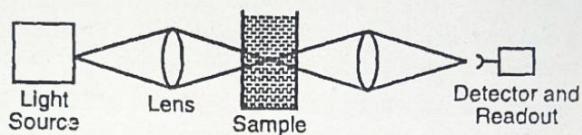


Fig. 15.1

In nephelometry, the light is also allowed to pass directly through the sample solution having suspended particles. The amount of radiation scattered by the particles is measured at an angle (usually 90°) to the incident beam. The measurement of the intensity of the scattered light as a function of the concentration of the dispersed phase forms the basis of nephelometric analysis. This is illustrated in Fig. 15.2.

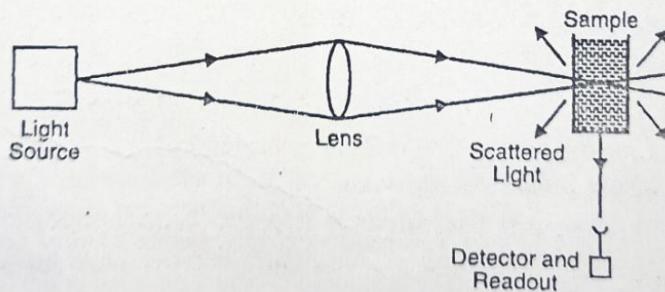


Fig. 15.2

### 15.2 Turbidimetry and Colorimetry

Turbidimetry is much similar to colorimetry because both involve measurement of the intensity of light transmitted through a medium. But these differ in the sense that the light intensity is decreased by

turbidimetry and by the absorption in colorimetry. Due to this reason both techniques may use similar or even identical apparatus.

### 15.3 Nephelometry and Fluorimetry

Nephelometry is much similar to fluorimetric method because both involve the measurement of scattered light. But the basic difference is that the scattering is elastic in fluorimetry and inelastic in nephelometry. It means that both incident and scattered light are of the same wavelength in nephelometry whereas the scattered light measured in fluorimetry is of a longer wavelength than the incident light.

### 15.4 Choice Between Nephelometry and Turbidimetry

The choice between a nephelometric and turbidimetric analysis depends upon the amount of light scattered by suspended particles present in the solution. Turbidimetry is satisfactory for determining relatively high concentrations of suspended particles because the scattering is quite extensive due to the presence of many particles. On the other hand nephelometry is most suited when the suspension is less dense and decrease in power of the incident beam is small. In such a case, more accurate results are obtained due to the small amount of scattered light which would be measured against a back background. In such an instance, turbidimetry should not be used since a comparison would have to be made of two large quantities of nearly equal values.

### 15.5 Theory

(1) Reflection vs. Scattering. Both reflection and scattering phenomena are very important in turbidimetry and nephelometry. If light is allowed to pass through a solution having suspended particles, reflection will take place if the dimensions of suspended particles are larger than the wavelength of incident light. On the other hand, scattering will take place if the dimensions of suspended particles are of the same order of magnitude or smaller than the incident wavelength. This distinction plays an important role in nephelometry and turbidimetry because it affects the sensitivity of the measurement as well as how the measurement is made. This can be seen from the following discussion :

- In nephelometric measurements, the suspended particles should be small with respect to the wavelength used. This is required so that scattering rather than reflection predominates. At the same time, smaller particles undergo scattering to give rise a symmetrical pattern of secondary rays in space having maximum intensity at  $90^\circ$  to the primary incident beam. Due to this reason, most of the instruments used in nephelometry involve measurements at  $90^\circ$ .

If the particles are larger, a small fraction of light gets deviated at right angle to the primary beam whereas the larger fraction gets deviated at angles other than  $90^\circ$ . In such cases, nephelometric measurements are made at angles less than  $90^\circ$  from the primary beam, say in the region  $5^\circ$  to  $20^\circ$ , or even  $45^\circ$ .

In nephelometry, suspended particles should neither be too large nor too small otherwise the scattering efficiency falls off. For measurements to be made in the ultraviolet and visible regions of spectrum the optimum particle size should be in the range of about 0.1 to  $1\ \mu\text{m}$ .

- In turbidimetric measurements, particles larger than the wavelength of light do not pose much problem because measurement depends on the total radiation removed from the primary beam irrespective of the mechanism by which it is removed or the angle through which it undergoes deviation. But with larger particles another problem arises, i.e., the relationship between absorbance and concentration does not remain linear. Thus, in such cases measurements cannot be very accurate.

(2) Factors Affecting Measurements. The amount of radiation removed or deviated from the primary radiation beam depends on the following factors :

- Concentration. In turbidimetry, one measures the transmittance of a primary beam of radiation which is defined as follows :

$$T = \text{Transmittance} = \frac{I}{I_0} \quad \checkmark \quad (1)$$

where  $I_0$  denotes the intensity of incident light after passing through comparison cell containing solvent and  $I$ , the intensity of the light after passing through the cell containing the sample solution. The transmittance  $T$  is related to the concentration  $c$  of suspended material by an equation similar to Beer's law, i.e.,

$$S = \log \frac{I_0}{I} = kbc \quad \checkmark \quad (2)$$

where  $S$  is called turbidance due to scattering (analogous to the term absorbance),  $b$  is the path length, and  $k$  is proportionality constant known as turbidity coefficient. The value of  $k$  depends on the particle size and shape, wavelength and refractive indexes of the suspended and suspending media.

It is important to remark here that equation (2) holds good only for such small particles where Rayleigh's scattering is the main mechanism of attenuation and for dilute suspensions where multiple scattering is unlikely. But the suspension should not be too dilute otherwise the transmitted intensity  $I$  becomes equal to the incident intensity. In such a situation accurate measurement is not possible.

Equation (2) shows appreciable departures for real cases in analogous to departures from Beer's law. In turbidimetry, a working curve is prepared by plotting  $S$  vs. known concentrations of scattering material and then the unknown concentrations are observed from this curve by knowing their  $S$  values from the turbidimeter.

In nephelometry, one cannot relate the scattered intensity to the concentration by any simple theoretical equation. The reason for this is that the scattered intensity in nephelometry depends upon a number of complicated factors like the properties of the scattering suspension and the angle and geometry of the measuring instrument. The best equation will be that one which will relate the scattered intensity  $I_s$  to the concentration of suspended particles  $c$  by the approximate empirical equation such as :

$$I_s = k_s I_0 c \quad (3)$$

where  $k_s$  denotes the empirical constant for a particular system and  $I_0$  is the incident intensity and all measurements are carried out under identical conditions.

Whenever quantitative analysis is to be carried out in nephelometry, a working curve is obtained by plotting the concentration of suspended particles vs.  $I_s/I_0$  under carefully controlled conditions. But in most of the cases  $\log(I_0/I_s)$  is plotted vs.  $c$  to conform with the more usual spectrophotometric and turbidimetric practices.

(b) **Particle geometry**—In both turbidimetric and nephelometric analysis, the most critical factor is the control of particle size and shape. The ideal situation is that when all samples and calibration solutions with which they are compared should possess the same distribution of small medium, and large particles. This, in turn, means that one should prepare samples and standards under identical conditions. But this is not a simple task. [The conditions include concentration of reactants, temperature, agitation, pH, presence of non-reactants, temperature, the order of mixing of reactants and the time allowed for particle growth. If one does not maintain these conditions, one may get different sized particles which may introduce major error in turbidimetry and nephelometry.]

(c) **Wavelength of incident light**—In turbidimetry, the wavelength of incident light as an important factor. The general practice is to select such a wavelength where the sample solution does not absorb strongly. If the sample solution is colourless, one must use the incident light of the same colour. On the other hand if clear solutions are having dark particles, light in the red or even infrared region must be used where there is maximum absorption.

In nephelometry, absorption is much less of a problem. In such as case, white light is generally used as a convenience.

- (d) **Refractive index difference**—Best results are obtained when there is an appreciable refractive-index difference between the particle and its surrounding medium. Sometimes it is advantageous to change solvents in order to increase the refractive-index differences.

### 15.6. Comparison of Spectrophotometry, Turbidimetry and Nephelometry

If incoming radiant energy gets impinged upon particles suspended in a medium which is having a refractive index different from that of the suspended particles, the light which strikes the particles is transmitted at angles other than  $180^\circ$  from the incident light. This light is said to be scattered. Nephelometry involves the direct measurement of the scattered light, whereas turbidimetry involves the measurement of the decrease in the intensity of transmitted light (*i.e.*, that which is not scattered) in a suspension. Nephelometry is similar to fluorimetry in that the measurement, in both cases, is made at an angle to the incoming radiant energy, however, the process mechanisms are entirely different. Turbidimetry has been found to be similar to absorption analysis in that the measurement light is at  $180^\circ$  to the impinging light, but again the mechanisms are entirely different.

In most cases the radiant energy which impinges upon and gets absorbed by particles in solution is almost immediately remitted or dissipated as these particles return to their respective stable energy states. If the wavelength of the impinging radiation becomes greater than the particles size (as is usually the case), the emitted radiation is removed by destructive interference and the path of the light beam appears to be unchanged as it passes through the sample. *As the wavelength of impinging radiation approaches the particle size the scattered fraction of light becomes greater.*

In dilute suspensions the relationship between the impinging power,  $P_0$ , and the exiting power,  $P$ , of a parallel beam due to scattering at a particular wavelength is given as follows :

$$\log \frac{P_0}{P} = kbc$$

where  $P_0$  refers to the initial power of the beam,  $P$  is the power of the beam after it passes through the suspension,  $k$  is a constant (analogous to absorptivity),  $b$  is the path length, and  $c$  is the concentration.

The extent of scattering which takes place in a suspension has been found to depend upon three factors :

1. the number of particles (concentration)
2. the size and shape of the particles
3. the wavelength of light. Blue light is scattered to a larger extent than is red light.

Nephelometry and turbidimetry measurements are easily made on simple adaptations of a basic spectrophotometer. Figure 15.3 compares spectrophotometry, turbidimetry, and nephelometry processes and instruments. In comparing the absorption spectrophotometer and the turbidimeter, note the only difference is in the sample. In the absorption spectrophotometer the sample is a true solution, while in the turbidimeter it is a suspension. A comparison of the turbidimeter and nephelometer shows that both samples are suspensions but the angles of measurement are different.

The sensitivity of turbidimetric measurements has been greatly increased with the development of a system where a large end-on-detector is placed close to the sample. Scattered light up to angles of  $50^\circ$  may be collected. This is, in reality, a hybrid between the turbidimeter and nephelometer as we have defined them. Fluorimeters may be easily converted to sensitive nephelometers by removing the emission filter (if a filter instrument) or by adjusting the emission monochromator to zero or the same wavelength as the excitation monochromator (if a grating or prism instrument).

### 15.7 Instrumentation

Much of the instrumentation used in nephelometry and turbidimetry is very similar to spectrophotometric devices as described earlier. Only special features are described here.

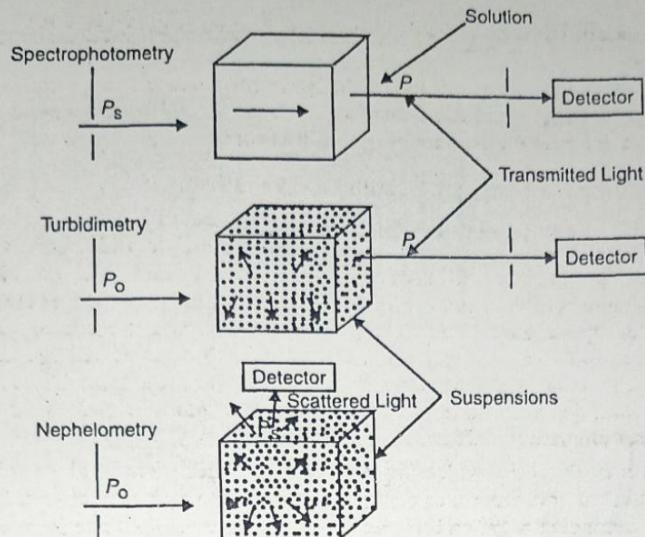


Fig. 15.3 : Comparison of spectrophotometry, turbidimetry, and nephelometry.  
The transmitted light,  $P$ , is measured in the spectrophotometer and turbidimeter.  
The scattered light,  $P_s$ , is measured in the nephelometer.

1. **Sources**—One may use white light in nephelometers but it is advantageous to use monochromatic radiation. Similarly, monochromatic radiation is used in turbidimeters to minimise absorption. In either case it is necessary to use sources providing high intensity monochromatic radiation and wherever possible short wavelengths are used to increase the efficiency of Rayleigh scattering. A mercury arc or a laser, with appropriate filter combinations for isolating one of its emission lines, is undoubtedly the most convenient source. However, if one has to determine the concentration of a particular material, a polychromatic source such as a tungsten lamp may be used. Even in such a case the best results are obtained if we use blue spectral region; a filter may be employed to block other wavelengths.
2. **Detectors**—In nephelometers photomultiplier tubes should be used as detectors because the intensity of scattered radiation is usually very small. In most of the nephelometers, detector is generally fixed at  $90^\circ$  to the primary beam but for maximum versatility and sensitivity it is desirable to vary the detector angle which is generally close to the primary beam. In some nephelometers, the detector is mounted on a circular disc which allows measurement at many angles, i.e., at  $0^\circ$  and from  $30^\circ$  to  $135^\circ$ . The outer edge of the disc is usually graduated in degree and readable from the outside.  
In turbidimeters, ordinary detectors such as phototubes may be used :
3. **Cells**—Although we can use cylindrical cells, they must have flat faces where the entering and exiting beams are to be passed. This is to minimise reflections and multiple scatterings from the cell walls. In general, a cell with a rectangular cross section is preferred. Where measurements are to be made at angles other than  $90^\circ$ , semioctagonal cells (Fig. 15.4) are used. The octagonal faces (Fig. 15.5) will allow measurements to be made at  $0^\circ$ ,  $45^\circ$ ,  $90^\circ$  or  $135^\circ$  to the primary beam. Generally, walls through which light beams are not to pass are painted a dull black to absorb unwanted radiation and minimise stray radiation. In experimental cells, a blackened curved horn is frequently affixed to the wall directly opposite the entering beam to trap all the beam which is not scattered. Alternatively, one can put a light trap for this purpose in the cell of the chamber in which the cell is located.
4. **Turbidimeters**—In most of turbidity measurements, ordinary colorimeters or spectrophotometers may be used. Simple visual instruments like the Parr turbidimeter or the Duboscq colorimeter can also be

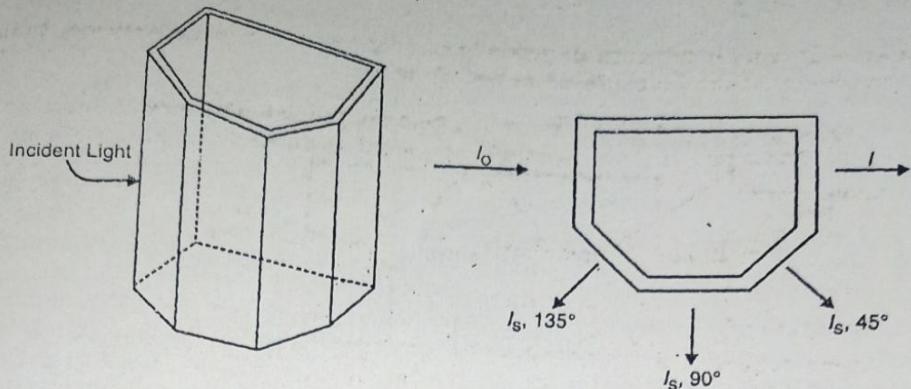


Fig. 15.4

Fig. 15.5

used. But the interesting turbidimeter is Du Pont model 430 which is more sensitive to low concentrations of suspended particles than an ordinary turbidimeter. This model is shown schematically in Fig. 15.6. This is a double-beam instrument which depends for its operation on the relative degree of polarisation of transmitted and scattered light.

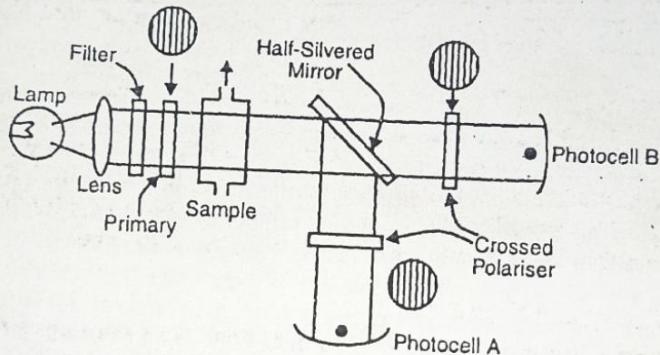


Fig. 15.6

The principle of Du Pont model 430 turbidimeter is that scattering by suspended particles present in solution changes the plane of polarisation of light. The beam of light obtained from the lamp is allowed to pass through the primary polarizer. This causes the incident beam to be plane-polarised. Then, the plane-polarised light is passed through the sample. After passing through the sample, the beam gets splitted up into two parts with the half-silvered mirror and then detected with two separate photocells. When sample solution is not having suspended particles, photocell A shows maximum response whereas photocell B shows minimum or zero response for the sample solutions having suspended particles. The ratio of signal B to signal A is considered to be a measure of the concentration of suspended particles. With the increase in the concentration of suspended particles in the sample, the response of photocell B increases while that of A decreases. Thus, the ratio of two signals is a sensitive measure of the turbidity.

Du Pont model 430 turbidimeter is advantageous to use because it involves the double beam arrangement which minimises the problem of absorption by the particles of the solution. This instrument can be used for the individual samples and also as an on-line monitor for flowing streams. This instrument is insensitive to colour of solvent or of particles or to lamp fluctuations. Du Pont model 430 turbidimeter cannot be used with solutions that contain optically active substances.

5. **Nephelometers**—Ordinary fluorimeters are generally used for nephelometric measurements. In some cases spectrophotometers can be employed as nephelometers.

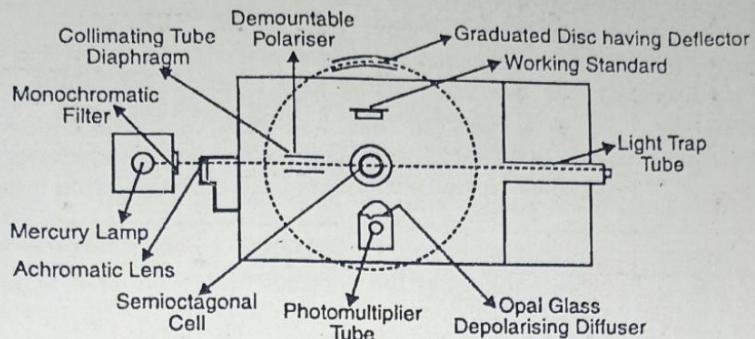


Fig. 15.7

Fig. 15.7 shows a representative precision nephelometer which works at low intensities. The multiplier phototube used as a receiver is mounted on a turnable and may be positioned at any desired angles from 0 to  $180^\circ$  relative to the exit beam. But for the most of nephelometric measurements it is generally positioned at  $45^\circ$  or  $90^\circ$  to the primary beam. The undeviated beam passes into black tube called a light trap.

The nephelometer shown in Fig. 15.7 can be used for the determination of particle size, shape and molecular weight in addition to nephelometric measurements.

A further modification to the nephelometer shown in Fig. 15.7 was suggested by Debye. According to him, the detector and turnable are kept in a closed compartment below the cell. Scattered radiation from the cell is intercepted by a small right-angle prism, also attached to the turnable, and reflected downward to the photomultiplier tube wherever a floor shutter is opened.

### 15.8 Applications of Turbidimetry and Nephelometry

Turbidimetry and nephelometry can be used on gaseous, liquid or even transparent solid samples in greatly varying proportions. The various applications of both these techniques are as follows :

1. **Inorganic Analysis**—In some cases, precipitates are difficult to filter due to small size or a gelatinous nature. In such cases, gravimetric operations cannot be performed. In these cases, nephelometry and turbidimetry can be used by converting the precipitates into ideal suspension under rigidly controlled conditions. This is done because the scattering of light depends on the size and number of the particles involved as well as their concentration.

When using nephelometry or turbidimetry for simple quantitative analysis, it is customary to prepare calibration curves from samples of known metal concentrations. The results of suspensions of unknown concentrations are obtained from these calibration curves.

The important uses of nephelometry and turbidimetry are the determination of sulphate as  $\text{BaSO}_4$ , carbonate as  $\text{BaCO}_3$ , chloride as  $\text{AgCl}$ , fluoride as  $\text{CaF}_2$ , cyanide as  $\text{AgCN}$ , calcium as oxalate or oleate, and zinc as ferrocyanide. Out of all these, sulphate determination is of particular importance and serves for the routine determination of total sulphur in coke, coal, oils, rubbers, plastics and other organic substances. In order to determine sulphur, it is first of all converted into sulphate. Then it is shaken with sodium chloride solution and excess of solid barium chloride to get a suspension of barium sulphate. Finally this suspension is subjected to nephelometry or turbidimetry as the case may be and the concentration of suspension may be computed from the calibration curve.

Another important application of nephelometry and turbidimetry is the determination of carbon dioxide. The method involves the bubbling of the gas through an alkaline solution of a barium salt and then analyzing for the barium carbonate suspension with nephelometry or turbidimetry.

The nephelometric and turbidimetric methods are more precise and sensitive than colorimetric methods. For example, phosphorus can be estimated at a concentration of 1 part in more than 300 million parts of water as a precipitate with strychnine-molybdate reagent. Similarly ammonia at a concentration of 1 part in 160 million parts of ammonia can be detected by adding Nessler's reagent.

The above described methods are widely used in water treatment plants, in sewage works and in power and steam generating plants. In water treatment plants, methods are used in the analysis of water for the determination of clarity and for the control of treatment processes.

Some turbidimetric and Nephelometric methods are given in Table 15.1.

Table 15.1 : Some Turbidimetric and Nephelometric methods

| Element         | Method | Suspensions                     | Reagent                                      | Interferences                         |
|-----------------|--------|---------------------------------|--|---------------------------------------|
| Ag              | T, N   | AgCl                            | NaCl   | —                                     |
| As              | T      | As                              | KH <sub>2</sub> PO <sub>4</sub>              | Ag, Hg, Pd, Pb,                       |
| Au              | T      | Au                              | SnCl <sub>2</sub>                            | Ru, Se, Te                            |
| Ca              | T      | CaC <sub>2</sub> O <sub>4</sub> | H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> | Mg, Na, SO <sub>4</sub> <sup>2-</sup> |
| Cl <sup>-</sup> | T, N   | AgCl                            | AgNO <sub>3</sub>                            | Br <sup>-</sup> , I <sup>-</sup>      |
| Se              | T      | Se                              | SnCl <sub>2</sub>                            | Te                                    |
| Te              | T      | Te                              | NaH <sub>2</sub> PO <sub>4</sub>             | Se                                    |

T = Turbidimetric, N = Nephelometric

- Organic Analysis—In food and beverages, turbidimeter is used for analysis of turbidity in sugar products, and clarity of citrus juices. Another interesting application is the determination of benzene in alcohol by dilution with water to make an immiscible suspension.
- Biochemical Analysis—An important application of turbidimetry is to measure the amount of growth of a test bacterium in a liquid nutrient medium. It is also used to find out the amount of amino acids, vitamins and antibiotics. Nephelometry has been used for the determination of protein and the determination of yeast, glycogen and of beta and gamma globulin in blood serum and plasma.
- Air and Water Pollution—Turbidimetry and nephelometry are used for the continuous monitoring of air and water pollution. In air, dust and smoke are monitored whereas in water, turbidity is monitored.
- Turbidimetric Titrations—These titrations may be carried out in a manner analogous to photometric titrations. In these titrations, the absorbance is to be plotted against the volume of titrant added. With the increase in the volume of titrant, the concentration of precipitate increases and hence the absorbance increases. When all the substance gets precipitated, the absorbance become constant. Thus, an abrupt change in the slope indicates the end-point. Turbidimetric titrations are shown in Fig. 15.8.

In Fig. 15.8, curve 1 is ideal, curves 2 and 3 might result from precipitates with mixed particle size, poor stirring, etc. In the case of curves 2 and 3, the detection of end point is highly complicated.

Turbidimetric titration can be used in the  $10^{-5}$  to  $10^{-6}$  formal range, with an average relative error  $\pm 5$  per cent or more.

In order to carry out turbidimetric titrations, the apparatus required is very simple. It generally consists of a light source and a photocell placed on the opposite side of the titration vessel.

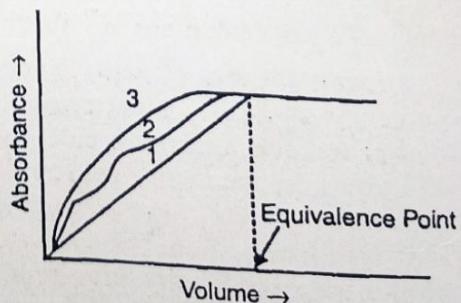


Fig. 15.8

Turbidimetric titrations include the titration of fluoride with calcium, bromide with silver, and sulphate with barium. By turbidimetric titration, silica may be determined in the approximate concentrate range of 0.1 to 150 ppm  $\text{SiO}_2$ .

6. **Phase Titrations**—Turbidimetry can be used for titrating a mixture of two liquids by a third which is miscible with one but not with the other. Addition of a sufficient quantity of the third liquid will result a separation of phase causing turbidity. In order to interpret the results, one should have knowledge of the three-component phase diagram or one should titrate unknown with known mixtures. In Fig. 15.9, a titration curve is shown for titration of water-pyridine mixture by chloroform.
7. **Determination of Molecular Weights of High Polymers**—The measurement of the intensity of light scattered by polymer solutions constitutes an important method for determining molecular weights of macromolecules. The turbidity of a sol of macromolecule is related to its molecular weight by the following relation.

$$\text{Limit} \frac{\text{HC}}{\text{C} \rightarrow 0 \text{ Turbidity}} = \frac{1}{M}$$

where H is a constant for a given polymer and a given dispersion medium, C is the concentration of the solution in grams per ml and turbidity is fraction of incident light scattered per cm length of the solution through which it passes. In order to determine molecular weight of a polymer turbidity is measured at different concentrations of its solution in a suitable solvent. The plot of (HC/turbidity) against concentration is then extrapolated to zero concentration as shown in Fig. 15.10. The intercept gives the value of 1/M.

8. **Atmospheric Pollution**—Smokes and fogs are visible largely due to light scattering effects. Thus instruments for measuring these effects are very useful in monitoring atmospheric pollution.

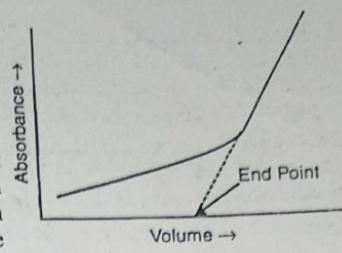


Fig. 15.9

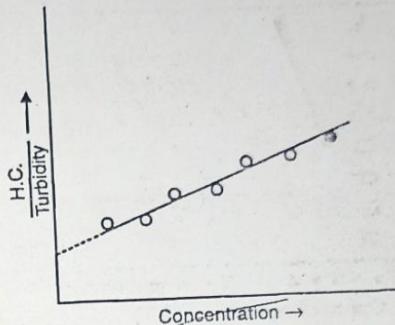


Fig. 15.10

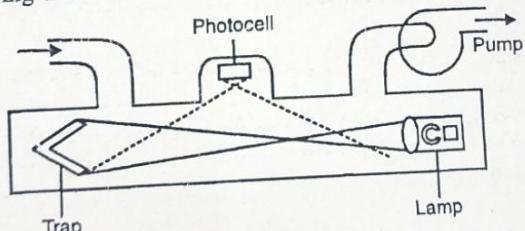


Fig. 15.11 : Nephelometric analyser for atmospheric particulates.

A portable instrument which can be operated in an automobile or air craft is shown in the Fig. 15.11. A beam of light from the lamp is passed through a distance of about 60 cm to a light trap. Air is pulled through this region by a suction pump. A photo cell is situated to one side and baffled so as to receive scattered radiation from the shaded area only.

#### TEST YOUR KNOWLEDGE

- Q.1. Compare the relative sensitivities of the nephelometer and turbidimeter.
- Q.2. Compare the nephelometer, turbidimeter and spectrophotometer, as to the type of samples.

### Effects of particulates on material

Particulate affect a verity of materials in various ways.

1. Particulate accelerate corrosion of metal.
2. They cause damage to building.
3. They cause damage to paints and furniture.

### Control of Particulates

Particulates can be control by using suitable control device. These devices include

1. Gravity settling chamber
2. Cyclone separator
3. Wet Scrubbers
4. Fabric Filter
5. Electrostatic Precipitator.

### 3.6.2 Secondary Air Pollutant—Sources, Effects and Control

Secondary pollutants are produced in the air by the interaction among two or more primary pollutants or by reaction with normal atmospheric constituents, without photo activation.

Such as:

1. Acid Rain
2. Formation of acid mists
3. Smog
4. Ozone
5. Per oxy acetyl nitrate (PAN) etc.

#### 3.6.2(a). Acid Rain

Normal rain water is always slightly acidic because of the fact that  $\text{CO}_2$  present in the atmosphere gets dissolved in water to form carbonic acid ( $\text{H}_2\text{CO}_3$ ). Because of the presence of  $\text{SO}_2$  and  $\text{NO}_2$  gases as pollutants in the atmosphere, the pH of the rain water is further lowered, often to as low as 2.4 and this type of precipitation of lower pH is called acid rain.

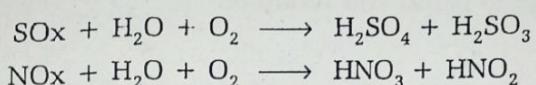
Acid Rain is becoming a problem all over the world, particularly in North Eastern America, North Western Europe and India. Norway, Germany, UK, USA, USSR (now CIS) and Canada.

#### Definition of Acid Rain

The term acid rain was first used by Robert Angus in 1872. "Literally it means the presence of excessive acids in rain waters". Acid rain is infect cocktail of mainly  $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$  where the ration of these two may vary depending upon the relative quantities of oxides of sulphur and nitrogen emitted.  $\text{H}_2\text{SO}_4$  is the major contributor (60–70%) to acid precipitation,  $\text{HNO}_3$  ranks second (30–40%) and  $\text{HCl}$  third (in very little amount).

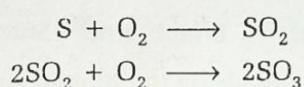
*Formation of Acid Rain*

Actually acid rain is the one phase of acid deposition which can either be wet or dry. Acid rain snow, dew, fog, frost and mist represent the wet form of deposition, which dust particles containing sulphates and nitrates, settled on earth, is called dry deposition. However, the wet rain is much more common.

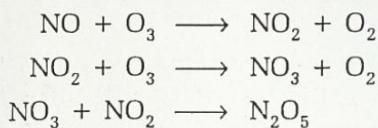
*Chemical Reaction*

Coal, fuel wood or petroleum contains sulphur and nitrogen, are converted into their respective oxides ( $\text{SO}_2$  and  $\text{NO}_x$ ) by combustion, which are highly soluble in water. By anthropogenic and by natural sources, oxides of sulphur and nitrogen enter the atmosphere.

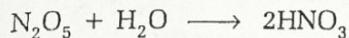
In case of sulphur, following reaction are involved.



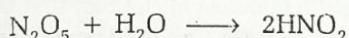
In case of nitrogen, following reaction are involved.



Under the humid conditions of air,  $\text{N}_2\text{O}_5$  invariably reacts with water vapours to form droplets of  $\text{HNO}_3$ .



Some  $\text{HNO}_2$  is also formed.



$\text{HNO}_3$  and  $\text{HNO}_2$  then return to the earth's surface.

$\text{HNO}_3$  and  $\text{H}_2\text{SO}_4$  thus formed combine with  $\text{HCl}$ , generate precipitation which is commonly referred to as acid rain.

Normally rain is weakly acidic and has a pH of 5.6, because  $\text{CO}_2$  from the air reacts with water to form  $\text{H}_2\text{CO}_3$ . Acid rain with pH 4 is 100 times more acidic than distilled water with pH 7. Pure rain water has a pH of about 5.5 to 5.7 but due to  $\text{SO}_2$  emissions, the pH of rain can drop as low as 2.0.

*Theory of Acid Rain*

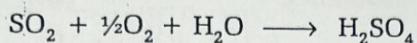
**Oxidation of Sulphur dioxide:** The principal chemical reaction of  $\text{SO}_2$  in air is oxidation to  $\text{SO}_3$  which reacts with moisture to give  $\text{H}_2\text{SO}_4$ . The  $\text{H}_2\text{SO}_4$  or its sulphates occur as aerosols. Oxidation step appears to proceed in three ways:

- (1) Catalytic Oxidation
- (2) Photo-chemical Oxidation
- (3) Oxidation by Radicals

#### (1) Catalytic Oxidation

The  $\text{H}_2\text{SO}_4$  is formed slowly in clean air. But it is catalyzed by aerosol containing metal ions of Cu (II), Fe (II), Mn (II) and oxides of Pb (II), Ca (III) and Al (III).

The presence of hydrocarbons and oxides of nitrogen are responsible to speeds up the oxidation rate of the reaction.



Even dust particles are also known to be strongly involved in catalyzing the oxidation of  $\text{SO}_2$ . Building surfaces may also act as catalytic centers.

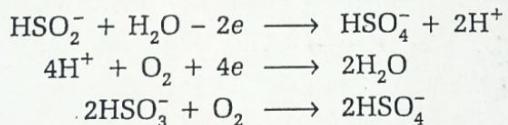
Increase in acidity inhibits the reaction, which proceeds best in neutral or alkaline medium. Since the reaction produces  $\text{H}_2\text{SO}_4$  it slows down as acid accumulates. The formation of  $\text{SO}_3^{2-}$  and  $\text{HSO}_3^-$  from  $\text{SO}_2$  in water are suppressed by increasing acidity driving reaction.

Decreasing the solubility of  $\text{SO}_2$  in the droplet. The solubility of  $\text{SO}_2$  in water is a function of pH.

Thus sulphur components in water are either covalent  $[\text{SO}_2(aq)]$  and  $\text{H}_2\text{SO}_3$  or ionic  $\text{SO}_3^{2-}$ ,  $\text{HSO}_3^-$  and  $\text{S}_2\text{O}_5^{2-}$ .

Ionic species are polar and so they are more soluble in water.  $\text{SO}_2$  solubility rises above pH 4 but drops markedly below pH 4. Addition of base like  $\text{NH}_3$  accelerates the reaction rate by reducing the acidity and forming main sulphate aerosols, i.e.,  $(\text{NH}_4)_2\text{SO}_4$  and  $\text{NH}_4\text{HSO}_4$ .

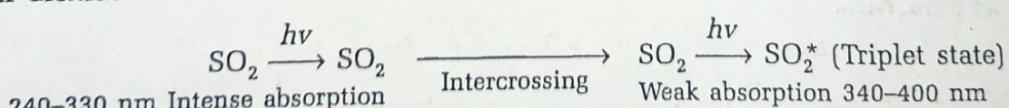
The reaction mechanism involves oxidation of sulphite species rather than  $\text{SO}_2$ .



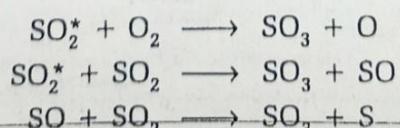
Metal catalysts act as an oxidant and may increase the rate of reaction 10–100 times.

#### (2) Photochemical Oxidation

Sulphur dioxide absorbs radiation and is raised to excited states:



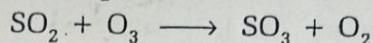
The triplet state has long life period and may react by several routes to give  $\text{SO}_3$ . For example,



Reaction achieves nearly 0.1 to 0.2% conversion of  $\text{SO}_2$  (of 5 to 30 ppm) to  $\text{SO}_3$  per hour.

### (3) Oxidation by Radicals

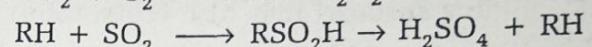
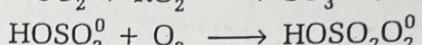
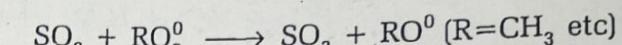
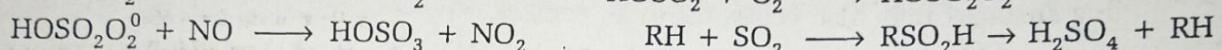
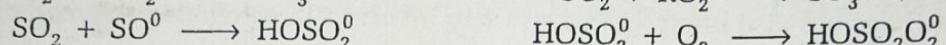
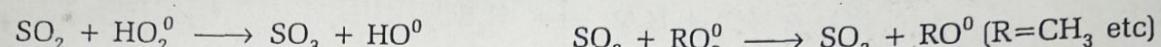
Both hydrocarbons and nitrogen dioxide accelerate the oxidation of  $\text{SO}_2$  as do radicals and peroxy compounds. These compounds are either secondary products or components of automobile emissions. Oxidation of  $\text{SO}_2$  proceeds as



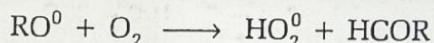
The reaction is slow in the gas phase but speeds up in presence of moisture.



Free radical mechanism proceeds as follows:



The hydroperoxy radical ( $\text{HO}_2^0$ ) in the above mechanism is formed by the reaction of alkoxyl radicals with  $\text{O}_2$ .



### Direction and Velocity of Wind in Acid Rain

The oxides of sulphur and nitrogen in the air, are to be oxidized into acids. For example, a given molecule of  $\text{SO}_2$  may remain in the atmosphere upto 40 hr, while a sulphate particle may remain for three weeks.

They have enough long life period and so these molecules may be wind transported several kilometres from their point of source.

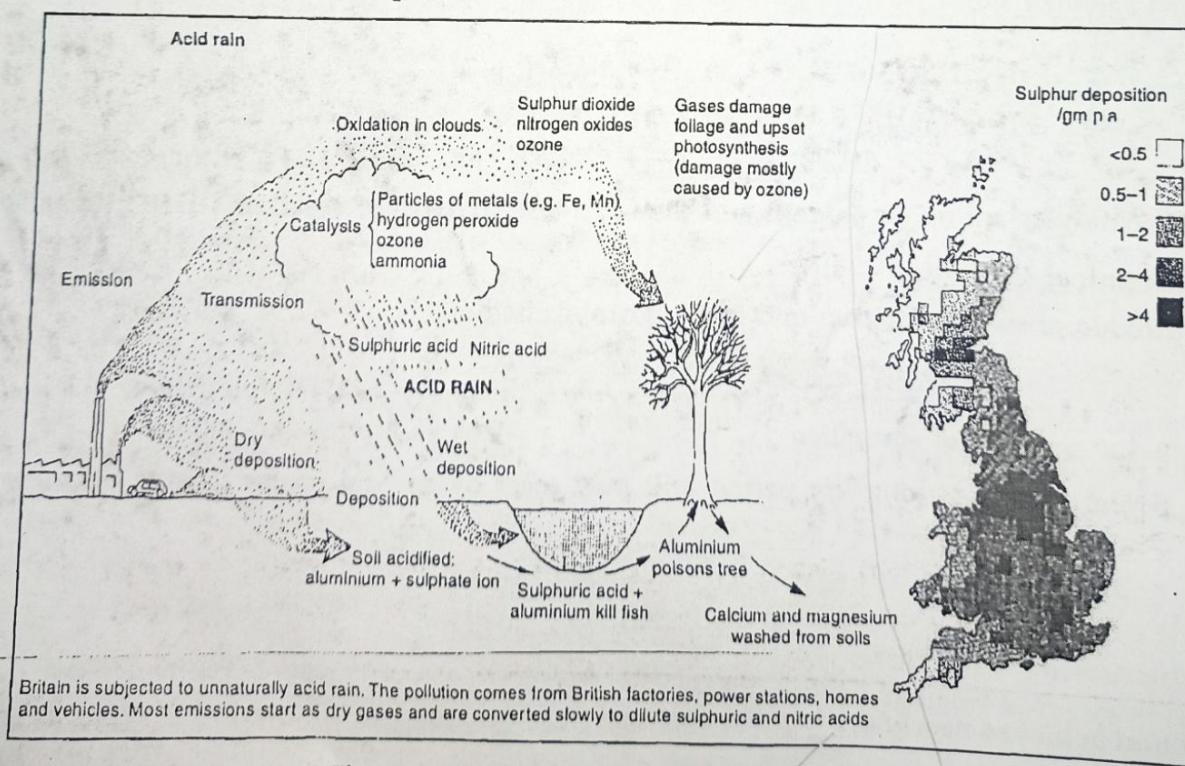


Fig. 3.5 Formation and deposition of acid rain

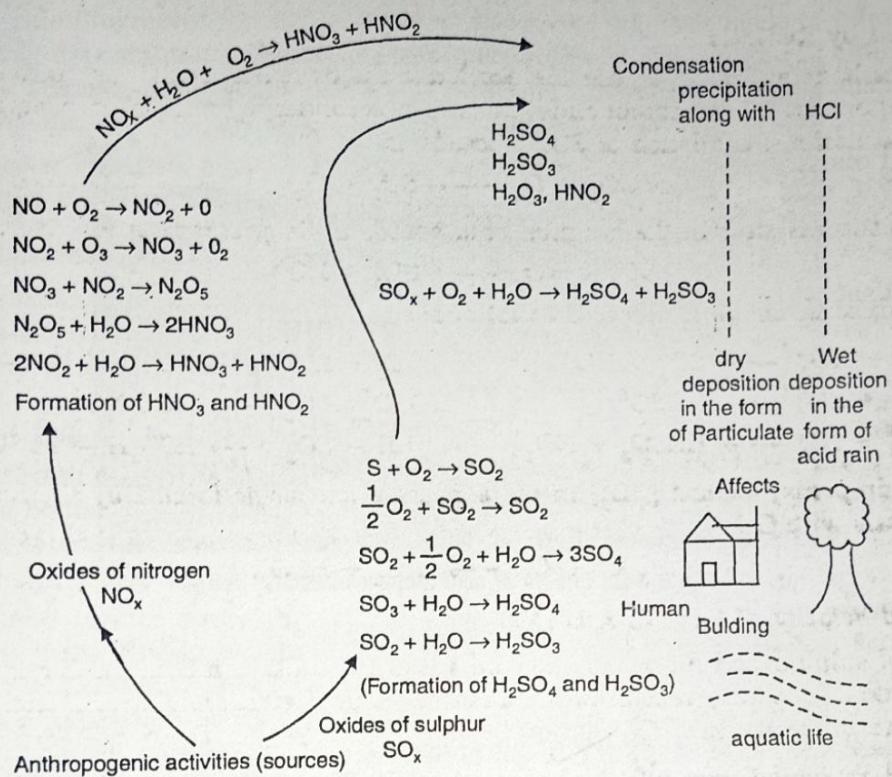


Fig. 3.6 Formation of acid rain

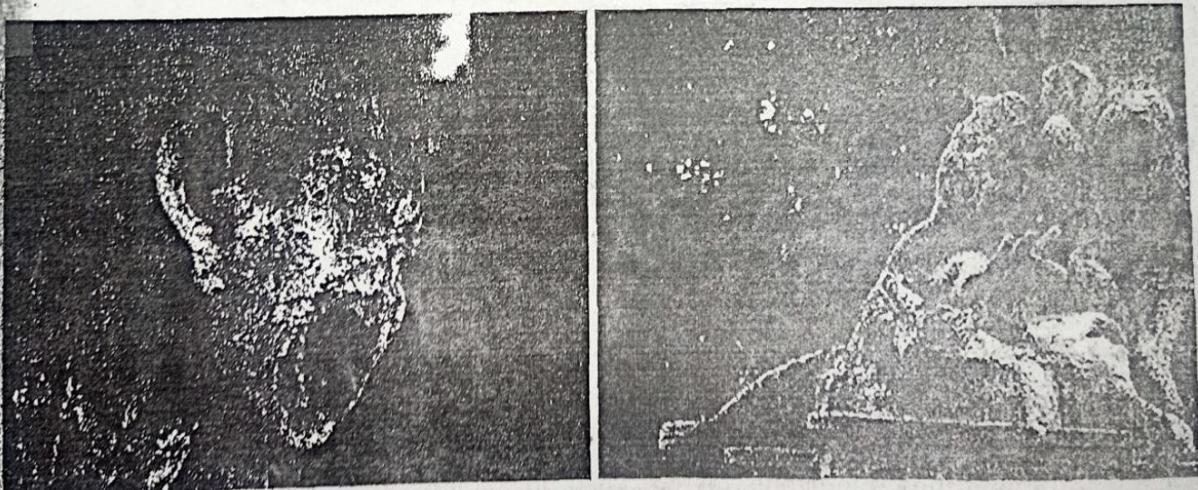


Fig. 3.7 (a) Effects of acid rain on bulding and moumentoes.

### 3. Effects by wet deposition of acid rain

The wet deposition increases the acidity of lakes and rivers which is made of inferior quality ecosystems. Wet deposition can transport some metals like Al, Cd, Hg and Cr into water and soil, lakes and streams, depleting the stocks of nutrients in the soil, thereby causing harm to various ecosystems.

Acidic water kills fish, algae, bacteria and aquatic system gets distorted into the sterility leaving a crystal cleat but ultimately a dead lock.

### Effects of Acid rain on Aquatic Ecosystem

1. The most important effect of acid rain on aquatic system is the decline in fish population. A significant reduction in fish pollution accompanied by decrease in the variety of species in food chain have been observed.
2. About 237 lakes in the Adirondack have a pH below 5, creating highly acidic level which is lethal for fishes. This acidic water can also leach aluminum from the soil. So the run off can carry dissolved aluminum to lakes, rivers and streams and other water bodies. It is highly toxic to aquatic animals and cause death of fish by clogging its gills and deprives it of oxygen. Further aluminum can also bind with organic particles, which are also toxic for fishes.
3. Different species react differently to acidified lakes. Adult fish can survive in more acidic water having high concentration of aluminum than fry fishes. Brook trout is most acid tolerant while rainbow trout the least so a few critically affected lakes still have a population of mature fish.
4. Many bacteria and blue green algae are killed due to the acidification, disrupting the whole ecological balance.

### Effect of Acid Rain on Terrestrial Ecosystem

The pH of the rain at Europe was 5.0 (in 1958) and the pH of rain at Netherlands was 4.5 (in 1962). This acid rain had damaged leaves of plants and trees and has retarded the growth of Swedish forests.

In West Germany, about 10% of the forests died and nearly 18 million acres of forests are severely affected by acid rains. Some effects are give below:

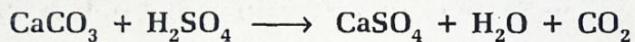
1. Nutrients such as calcium, potassium, iron and magnesium have been leached away from soil by acids. These nutrients are most essential for the growth of plant.
2. Acidic rain destroyed crops and forests, reducing agricultural productivity.
3. Recently the effect of acid precipitation on terrestrial vegetation indicates reduced rate of photosynthesis and growth and increased sensitivity to drought and disease.
4. Acid rain has severely retarded the growth of crops such as pea, beans, potato, spinach, broccoli and carrots etc.
5. The activity of symbiotic nitrogen fixing bacteria present in the nodules of leguminous family, is inhibited, thereby destroying the fertility of the soil.
6. Root systems are damaged by the uptake of aluminum released from the soil. Nitrates may be leached from the soil by acid run off waters.
7. Acid deposition weakens the trees such as pine, spruce, ashes, and birch which can be easily attacked by pathogens and drought.

**Effect of Acid Rain on Lake Ecosystem**

1. Acid rain causes a number of complications in ponds, rivers and lakes, where it accumulates as acid snow. During summer rapid snow melt gives a jolt of acid water to lakes. This acid jolt is most damaging to young fish, algae, and insects and to the food chain.
2. Acid lakes have low levels of phytoplankton. Snails, clams, oysters etc. having their shells of calcium carbonate, are among the first animals to perish in acidic lakes.
3. Black flies, mosquitoes, deer flies and other aquatic worms occur abundantly where fishes are eliminated. So they appear to thrive in acid conditions. Dragon fly larvae and water boatmen also flourish in acidified lakes.
4. The activity of the bacteria and other microscopic animals are reduced in acidic water. So the dead materials and other accumulated substances lying on the bottom of lakes are not rapidly decomposed. Consequently essential nutrients as nitrogen and phosphorus stay locked up in plant and animal remains. Biomass production is reduced and fish pollution declines.
5. Aquatic plants do not grow in acid water. This could affect the feeding and breeding habits of aquatic species.

**Effect of Acid Rain on Buildings**

1. Acid rain causes extensive damage to buildings and structural materials of marble limestone, slate and mortar etc. Limestone is attacked rapidly.



The attack on marble is termed as **Stone leprosy**.

2. In Greece and Italy, invaluable stone statues have been partially dissolved by acid rain. The Taj Mahal in Agra is also suffering at present due to SO<sub>2</sub> and H<sub>2</sub>SO<sub>4</sub> acid fumes or air pollutants released from Mathura refinery.
3. Acid rain also corrodes houses, monuments, statues, bridges, fences and railings that cost the world 1450 million dollars a year. British Parliament Building also suffered damage due to H<sub>2</sub>SO<sub>4</sub> rains.
4. Due to acidity levels of heavy metals as Al, Mn, Pb, Cd, Cr and Cu in water increases beyond the safe limit which indirectly affects the buildings.
5. Acid rains are great threat to British environment. Much of the falling snow in Britain is now highly acidic. If it does not melt it may turn into a pollution time bomb.
6. H<sub>2</sub>S tarnishes silver and blackens leaded house paints. Ozone produces cracks in rubber. Traces of radio active elements present in radio active rain severely damage the buildings.

**Corrosion of water pipes due to acid rain**

Acidic water corrodes water pipes. This leads, of course, to more frequent pipe replacement, but more important, to the risk that metals leached from the pipe walls can reach humans directly through water consumption.

### *Effect of Acid Rain on Man*

1. Acidic rain has been found to be very dangerous to the living organisms as it can destroy life. Acidification can play havoc with human nervous system, respiratory system and digestive system by making the person an easy prey to neurological diseases. This is due to the highly toxic compounds produced by acid, these toxics contaminate the portable water and enter on the body of man.
2. Acidic rains containing air pollutants contribute to a variety of safety hazards associated with reduced visibility due to smog etc.
3. These contaminants can be nuisance in several aspects and cause adverse health effects.

### *Disease Spread by Rain Water*

Microbes in rain water have great influence on terrestrial phase of eco-system. They cause several plant infections or the **infections in the respiratory tract of animals**.

Micro-organisms present in rain water also play some role in spread of animal disease especially the **foot and mouth diseases of cattle and sheep**.

### *Control of Acid Rain*

There is an urgent need for proper regular monitoring to provide timely warning about acidification of our environment.

1. Short-term control of acid deposition problem can be achieved by using lime.
2. By avoiding or to reduce diesel fuel emissions because diesel emissions contain nitrogen oxides, which are known to cause **acid rain** and also diesel particles, some of which are carcinogenic in nature.

### **5.2(b) Smog (London Smog and Los Angeles Smog)**

The word **smog** is derived from **smoke and fog**. The **oldest smog**, which consists of a mixture of coal smoke and fog has plagued human beings since the 14<sup>th</sup> century.

Smog can be of two types:

1. **UK Smog or Coal induced smog:** It is a mixture of reducing smog and so it has been called as **Reducing Smog**; It is also termed as **sulphurous smog**.
2. **Photochemical or Los Angeles Smog:** It first clue cam in 1950. Los Angeles Smog consisting mainly a mixture of oxidizing pollutants is known as **oxidizing smog**.

### **Sulphurous or London Smog**

The most several air pollution ever occurred was due to sulphurous smog caused in **London in 1952** and hence the name **London Smog** was assigned. The mixture of smoke, fog and sulphur dioxide ( $\text{SO}_2$ ) which affected London so badly for several centuries after the introduction of coal as a fuel, is chemically a reducing mixture, so it is also called as a **Reducing Smog**.

The main components of London Smog were:

- (i)  $\text{SO}_x$
- (ii) Particulates, such as soot, ammonium sulphate etc.
- (iii) Humidity or water from fog.

***Photochemical Smog or Los Angeles Smog***

Los Angeles in California experienced a new and serious form of air pollution during **1944**, which was characterized by reduced visibility eye irritation (*i.e.*, lacrimation) and plant damages (*e.g.*, metallic sheen on leaves), whereas **London Smog** is characterized by bronchitis irritation. It is not related to smoke of fog. It is also called as **photochemical smog** as an important reaction, the dissociation of  $\text{NO}_2$ , is caused by sunlight.

**Smog** There is normally a cycle of formation and traffic density.

$\text{NO}_2$  under the action of ultra violet radiation from the sun, decomposes to NO and oxygen free radical ( $\text{O}^*$ ). This oxygen radical combines with  $\text{O}_2$  to form ozone (secondary pollutant). The  $\text{O}_3$  so formed in sunlight reacts with NO forming  $\text{NO}_2$  and raising its level.

This cycle is disrupted by the action of volatile organic compounds (VOCS). Hence the most pollution property of  $\text{NO}_2$  is that it acts as a precursor of peroxy acetyl nitrate (PAN) and ozone which are extremely lethal to living organisms. Actually PAN, a constituent of photochemical smog and  $\text{NO}_2$  is formed by the reaction of VOCS with hydroxyl radicals. NO and oxygen. VOCS also block the consumption of  $\text{O}_3$  by reconverting NO to  $\text{NO}_2$ .

**TABLE 3.9. Major Chemical Pollutants in Photochemical Smog: Sources and Environmental Effects**

| Toxic Chemical   | Sources  | Environmental Effects  | Additional Notes   |
|--|--|--|--|
| <b>Nitrogen Oxides (NO and <math>\text{NO}_2</math>)</b> | <ul style="list-style-type: none"> <li>- Combustion of oil, coal, gas in both automobiles and industry.</li> <li>- Bacterial action in soil.</li> <li>- Forest fires.</li> <li>- Volcanic action.</li> <li>- Lightning.</li> </ul> | <ul style="list-style-type: none"> <li>- Decreased visibility due to yellowish color of <math>\text{NO}_2</math>.</li> <li>- <math>\text{NO}_2</math> contributes to heart and lung problems.</li> <li>- <math>\text{NO}_2</math> can suppress plant-growth.</li> <li>- Decreased resistance to infection.</li> <li>- May encourage the spread of cancer.</li> </ul> | <ul style="list-style-type: none"> <li>- All combustion processes account for only 5 % of <math>\text{NO}_2</math> in the atmosphere, most is formed from reactions involving NO.</li> <li>- Concentrations likely to rise in the future.</li> </ul> |
| <b>Volatile Organic Compounds (VOCs)</b>                 | <ul style="list-style-type: none"> <li>- Evaporation of solvents.</li> <li>- Evaporation of fuels.</li> <li>- Incomplete combustion of fossil fuels.</li> <li>- Naturally occurring compounds like terpenes from trees.</li> </ul> | <ul style="list-style-type: none"> <li>- Eye irritation.</li> <li>- Respiratory irritation.</li> <li>- Some are carcinogenic.</li> <li>- Decreased visibility due to blue-brown haze.</li> </ul>   | <ul style="list-style-type: none"> <li>- The effects of VOCs are dependent on the type of chemical.</li> <li>- Concentrations likely to continue to rise in future.</li> </ul>   |

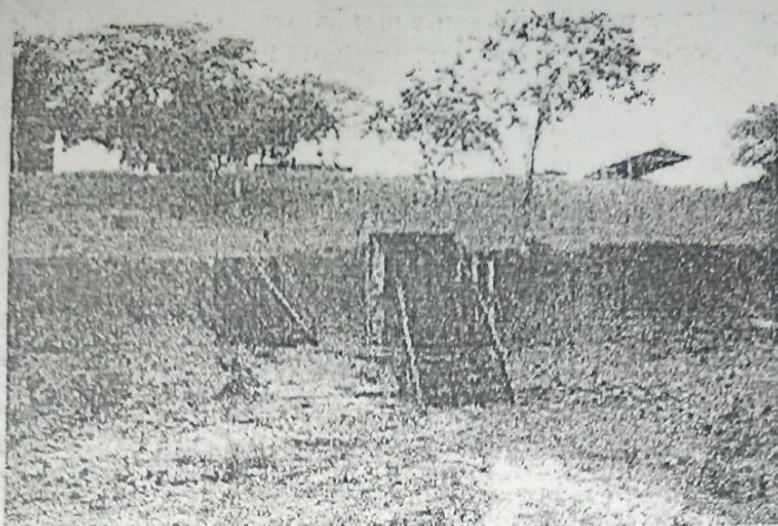


Fig. 3.7 (b) Effects of acid rain on trees and soil



Fig. 3.7 (c) Effect of acid rain on trees

#### *Adverse Effects of Acid Rain*

The direct effects of acid rain are determined by concentration of pollutants in the air.

##### **1. Effects by dry deposition of acid rain**

The dry deposition has several effects on the environment. It attacks building materials, predominantly limestone, sandstone, marble, steel, nickel and other metals causing a loss of millions of rupees which were spent in making structures like statues and buildings.

##### **2. Effects by gaseous deposition of acid rain**

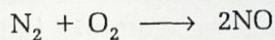
When pollutant deposited in gaseous form causes direct damage to plants and trees, the visible injury being gradual yellowing or depigmentation of leaf tissues called chlorosis.

|                             |  |  |  |
|-----------------------------|--|--|--|
| Ozone ( $O_3$ )             | <ul style="list-style-type: none"> <li>Formed from photolysis of <math>NO_2</math>.</li> <li>Sometimes results from stratospheric ozone intrusions.</li> </ul> | <ul style="list-style-type: none"> <li>Bronchial constriction.</li> <li>Coughing, wheezing.</li> <li>Respiratory irritation.</li> <li>Eye irritation.</li> <li>Decreased crop yields.</li> <li>Retards plant growth.</li> <li>Damages plastics.</li> <li>Breaks down rubber.</li> <li>Harsh odor.</li> </ul> | <ul style="list-style-type: none"> <li>Concentrations of 0.1 parts per million can reduce photosynthesis by 50%.</li> <li>People with asthma and respiratory problems are influenced the most.</li> <li>Can only be formed during daylight hours.</li> </ul> |
| Peroxyacetyl Nitrates (PAN) | Formed by the reaction of $NO_2$ with VOCs (can be formed naturally in some environments).   | <ul style="list-style-type: none"> <li>Eye irritation.</li> <li>High toxicity to plants.</li> <li>Respiratory irritation.</li> <li>Damaging to proteins.</li> </ul>  | <ul style="list-style-type: none"> <li>Was not detected until recognized in smog.</li> <li>Higher toxicity to plants than ozone.</li> </ul>  |

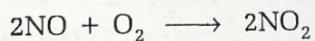
### Chemical Reactions Involved in the Formation of Photochemical Smog

The time variations in levels of  $O_3$ , NO,  $NO_2$  are explained in terms of chemical reactions first proposed by **Friedlander and Seinfeld**. The important steps are.

#### (1) Formation of Nitric Oxide (NO)



Some of this NO reacts further with oxygen to form nitrogen dioxide ( $NO_2$ )



Actually anthropogenic NOx is about 10% of the total in the atmosphere, while that the rest comes from natural bacterial action. Typical levels of NO and  $NO_2$  in the US are 0.002 ppm and 0.004 ppm respectively. In urban areas these levels often reach 100 times of these values.

#### (2) Nitrogen Dioxide is a Part of Photolytic $NO_2$ Cycle

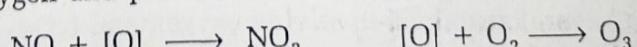
According to **Haagen Smit** theory, ultraviolet rays in the sunlight cause the photodissociation of  $NO_2$  to form NO and atomic oxygen.



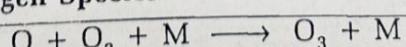
$NO_2$  being an efficient absorber of UV light is cleared at 400 nm.

#### (3) Formation of Oxidants

Formation of ozone, nascent oxygen and peroxide etc. during the smog formation.



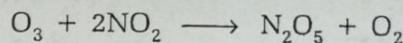
#### (4) Reactions Involving Oxygen Species



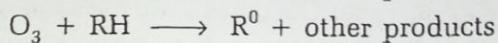
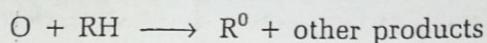
Where M being a body such as  $N_2$ ,  $O_2$ , Argon or  $CO_2$  which is capable of carrying off the larger excess energy.

**(5) Combination of  $O_3$  and  $NO_2$  to Close the Cycle**

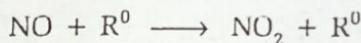
$O_3$  can also combine with  $NO_2$  to form nitrogen pentoxide.



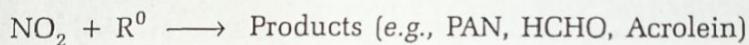
Hydrocarbons, which are emitted in automobile exhausts are believed to react by free radical mechanism either with [O] or  $O_3$  to form secondary pollutants such as aldehydes, ketones and organic peroxides.

**(6) Production of Organic Free Radical from Hydrocarbons RH**

$R^0$  is a free radical which may or may not contain oxygen. These free radicals then react with  $O_2$  or NO to produce other unstable intermediates and various by products. Often a series of 20 or more consecutive reactions are needed to account for all the products.

**(7) Chain Propagation Branching and Termination**

Where  $R^0$  contains oxygen and oxidises NO.



As a result of these chemical reactions the following changes take place.

(1) Hydrocarbons in the smog cycle generate free radicals which use up some of the ambient NO.

So,

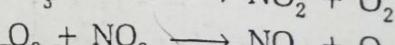
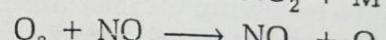
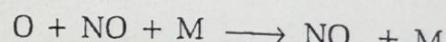
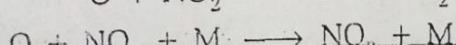
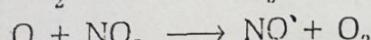
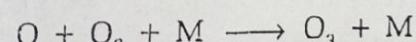
- (a) NO disappears
- (b) Ozone accumulates in the photolytic  $NO_2$  cycle.
- (c)  $NO_2$  is regenerated.
- (d) Ozone which is an extremely initiative pollutant even at low concentrations also reacts to produce other highly reactive organic oxidants, e.g., **secondary pollutants** such as acrolein, formaldehyde, peroxyacetyl nitrate (PAN) etc. **These secondary pollutants have deleterious effects and collectively form photochemical smog.**

The mechanism of smog formation includes the following chain of reactions:

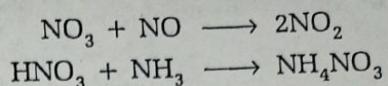
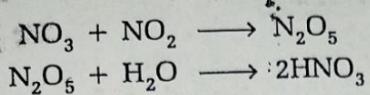
Formation of atomic oxygen by photochemical reaction,



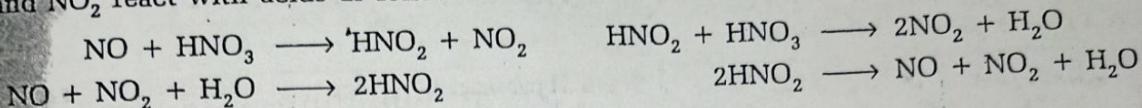
It leads to several reactions involving oxygen and  $NO_x$ .



A number of significant atmospheric reactions involving nitrogen oxides, were nitrous acid and nitric acid occur as,

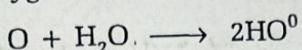


NO and  $\text{NO}_2$  react with acids as follows:

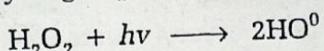


Highly reactive radicals  $\text{HO}^{\cdot}$  may be formed as under:

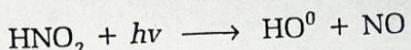
(a) When excited atomic oxygen reacts with water



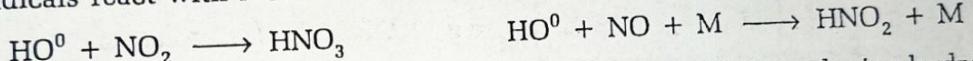
(b) Photodissociation of hydrogen peroxide



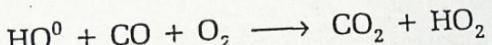
(c) By Photolysis of nitrous acid



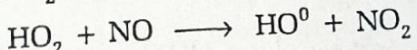
The radicals react with  $\text{NO}_x$



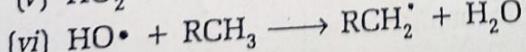
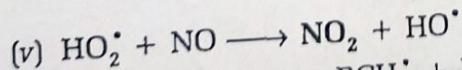
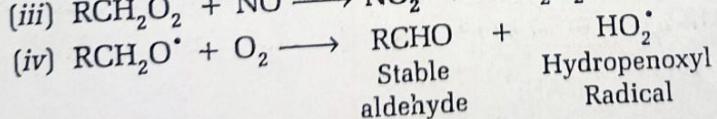
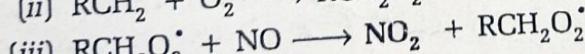
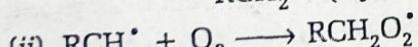
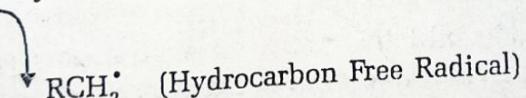
These radicals also react with atmospheric carbon monoxide (CO) producing hydroperoxy radical ( $\text{HO}_2^{\cdot}$ )



The  $\text{HO}_2^{\cdot}$  oxides NO into  $\text{NO}_2$  as,



(i) Reactive hydrocarbon +  $\text{O}_3$



Stable hydrocarbon

Overall in one cycle generate

Two molecules of  $\text{NO}_2$ , one stable Aldehyde.

One molecule of  $\text{RCH}_2^{\bullet}$ , to start all over again and one molecule of aldehyde. This aldehyde can react with  $\text{OH}^{\bullet}$  and  $\text{NO}_2$  and they form PAN.

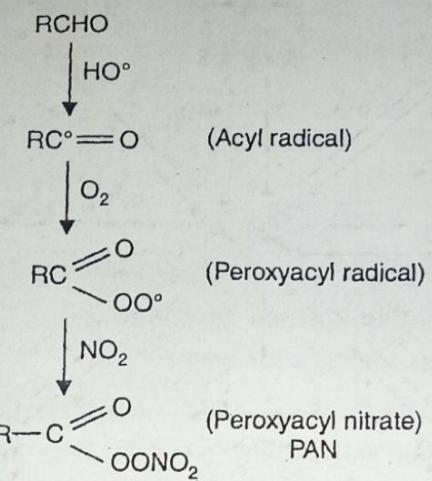


Fig. 3.8(a) Formation of peroxyacyl nitrate (PAN)

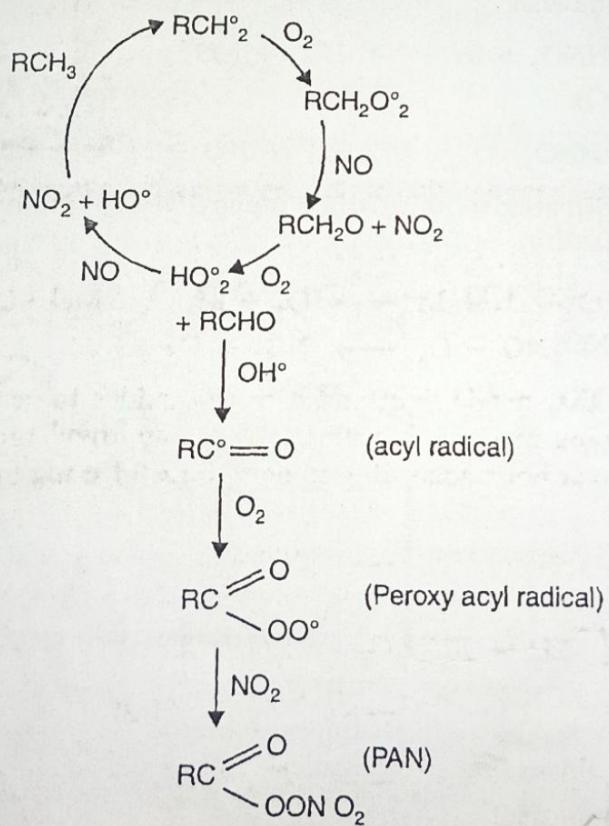


Fig. 3.8(b) Formation of PAN and photochemical smog.

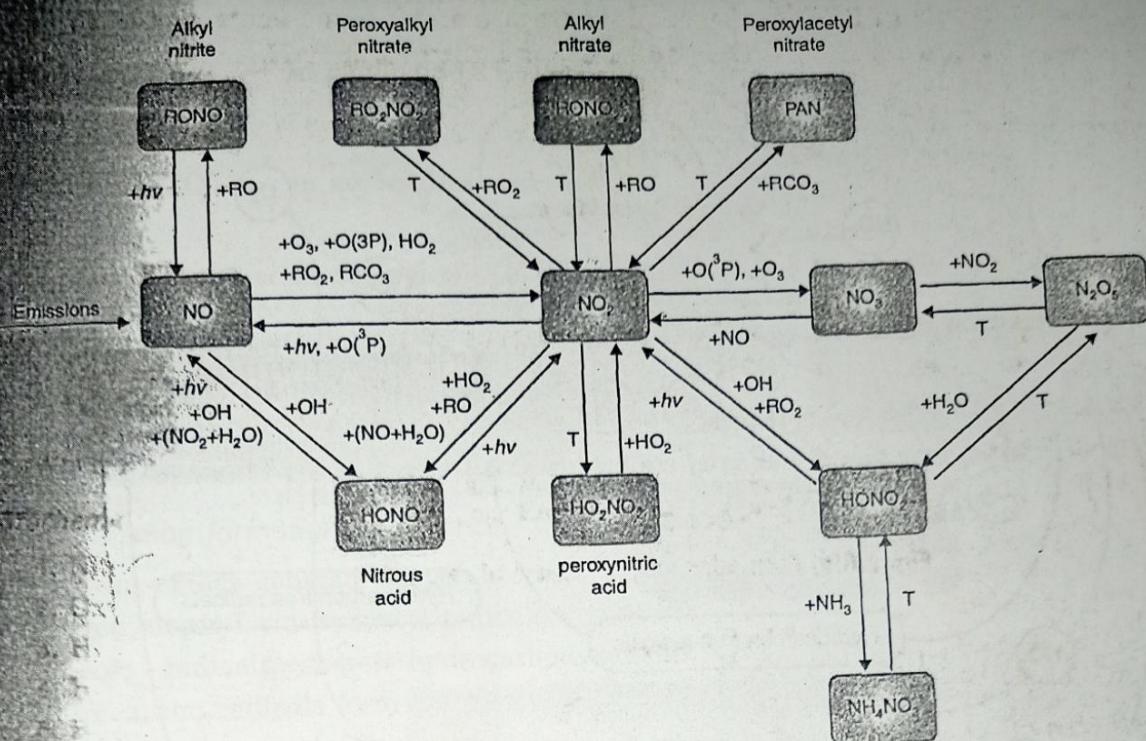
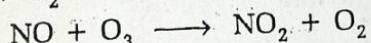
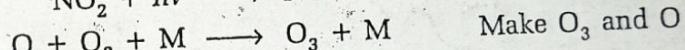
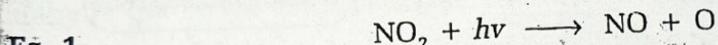


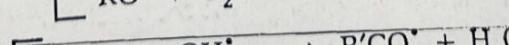
Fig. 3.9 Chemical transformation of nitrogen oxides in the troposphere



This is a cyclic process that needs light and nitrogen oxides to generate oxygen atoms. Once formed, the oxygen atoms react with water to form hydroxyl radicals. The hydroxyl radicals then react with hydrocarbons according to equations 5 through 8 to form peroxyacyl nitrates (or PAN).



then



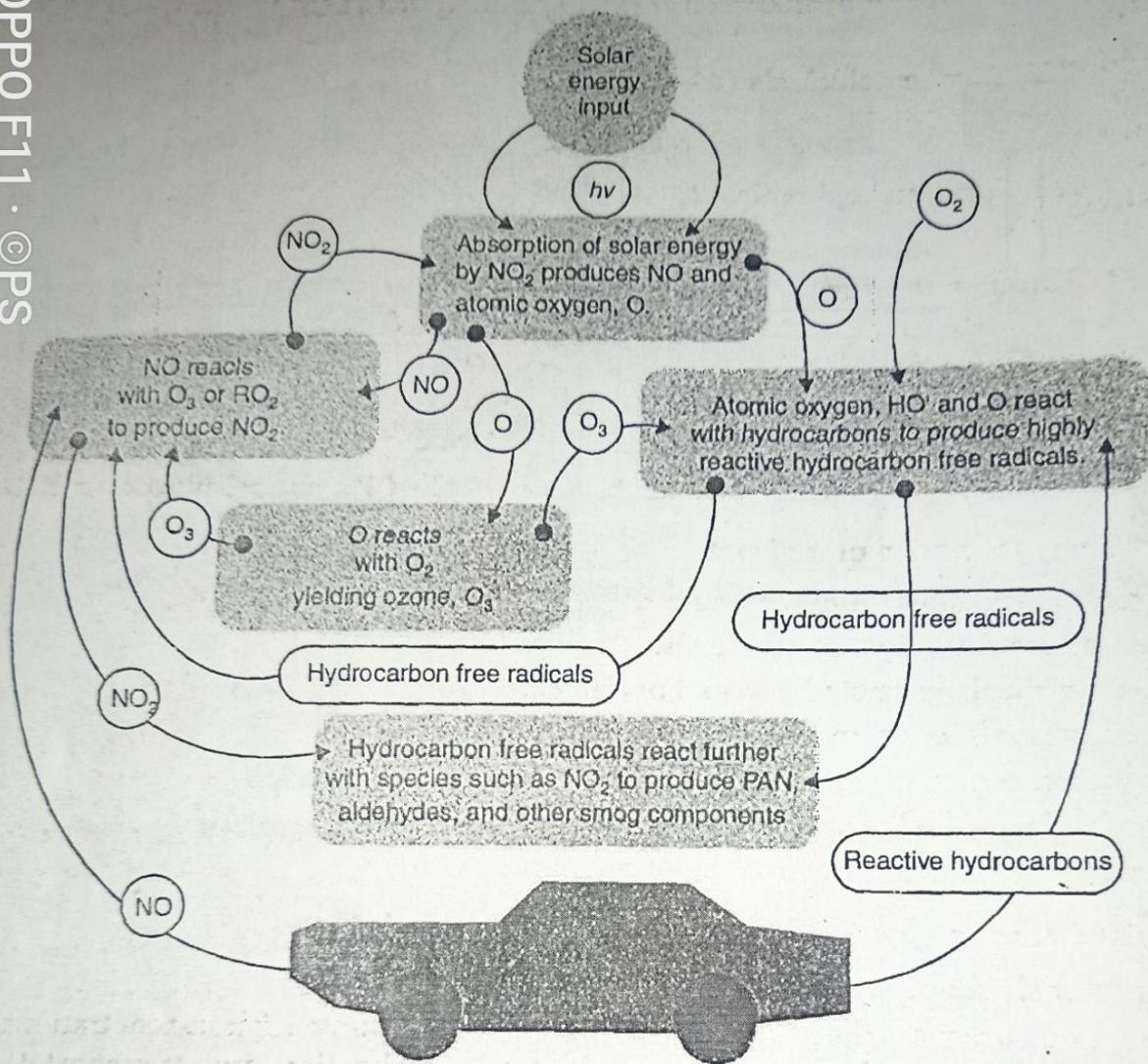
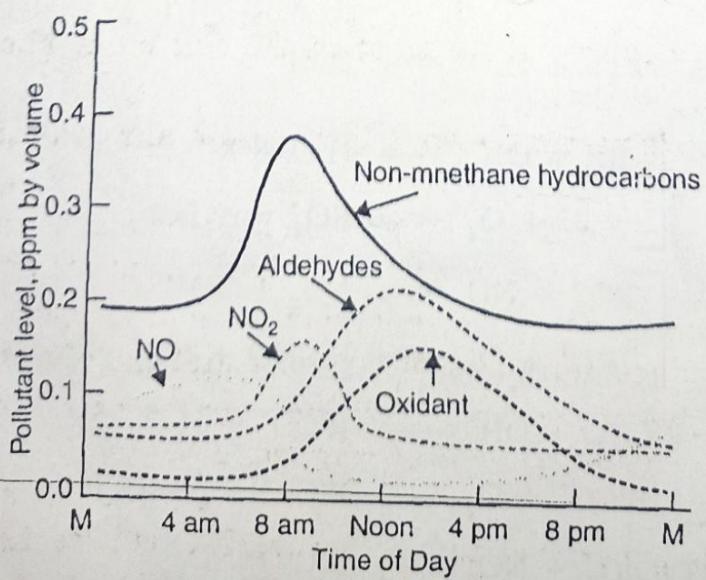
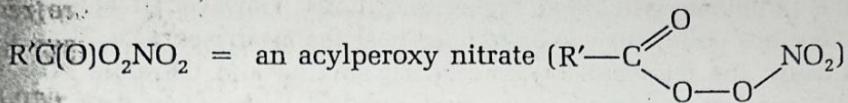
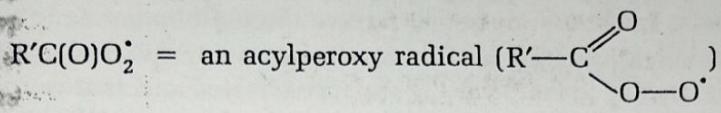
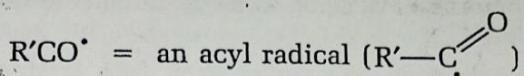
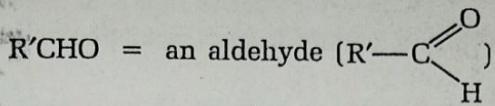


Fig. 3.10 Chemical transformations involved in the formation of photochemical smog



$\text{RH}$  = any hydrocarbon (i.e.,  $\text{CH}_3\text{CH}_2\text{CH}_3$  or  $\text{CH}_3\text{CH}_3$ )



When  $\text{R}'$  is a methyl group ( $\text{CH}_3-$ ) this substance is called Peroxyacetyl nitrate, or PAN.

#### *Photochemical smog formation at a glance*

1. Nitrogen oxides generate oxygen atoms.
2. Oxygen atoms form hydroxyl radicals.
3. Hydroxyl radicals generate hydrocarbon radicals.
4. Hydrocarbon radicals form hydrocarbon peroxides.
5. Hydrocarbon peroxides form aldehydes.
6. Aldehydes form aldehyde peroxides.
7. Aldehyde peroxides form peroxyacetyl nitrates.

#### *Certain conditions required for the formation of photochemical smog*

##### **These conditions include:**

1. A source of nitrogen oxides and volatile organic compounds. High concentrations of these two substances are associated with industrialization and transportation. Industrialization and transportation create these pollutants through fossil fuel combustion.
2. The time of day is a very important factor in the amount of photochemical smog present.
  - Early morning traffic increases the emissions of both nitrogen oxides and VOCs as people drive to work.
  - Later in the morning, traffic dies down and the nitrogen oxides and volatile organic compounds begin to react forming nitrogen dioxide, increasing its concentration.
  - As the sunlight becomes more intense later in the day, nitrogen dioxide is broken down and its by-products form increasing concentrations of ozone.
  - At the same time, some of the nitrogen dioxide can react with the volatile organic compounds to produce toxic chemicals such as PAN.
  - As the sun goes down, the production of ozone is halted. The ozone that remains in the atmosphere is then consumed by several different reactions.

3. Several meteorological factors can influence the formation of photochemical smog. These conditions include:
  - Precipitation can alleviate photochemical smog as the pollutants are washed out of the atmosphere with the rainfall.
  - Winds can blow photochemical smog away replacing it with fresh air. However, problems may arise in distant areas that receive the pollution.
  - Temperature inversions can enhance the severity of a photochemical smog episode. Normally, during the day the air near the surface is heated and as it warms it rises, carrying the pollutants with it to higher elevations. However, if a temperature inversion develops pollutants can be trapped near the Earth's surface. Temperature inversions cause the reduction of atmospheric mixing and therefore reduce the vertical dispersion of pollutants. Inversions can last from a few days to several weeks.
4. Topography is another important factor influencing how severe a smog event can become. Communities situated in valleys are more susceptible to photochemical smog because hills and mountains surrounding them tend to reduce the air flow, allowing for pollutant concentrations to rise. In addition, valleys are sensitive to photochemical smog because relatively strong temperature inversions can frequently develop in these areas.

#### *Concentration and Distribution of Hydrocarbons and Photochemical Oxidants*

The average concentration of hydrocarbons in urban air lies in the range of 0.03 to 0.10 ppm. Excluding methane which is not involved because of its lack of reactivity in photochemical reactions. Ozone is the real cause of polluted air with high photochemical oxidant levels.

At PAN concentration the polluted air lies in the order of 0.01 ppm which poses a threat to plants and animal life.

#### *Factors Affecting the Photochemical Reaction*

- ✓ 1. Light intensity
- ✓ 2. Hydrocarbon reactivity.
- ✓ 3. Ratio of hydrocarbons to nitric oxide.
- ✓ 4. Presence of light absorbers.
- ✓ 5. Meteorological variables.
- ✓ 6. Height and intensity of atmosphere.

#### *Effects of Photochemical Smog on Man*

1. Photochemical smog at a very low concentration of 0.01 ppm is reported to cause injuries to petunia, lettuce, bean, citrus, salad crops and coniferous trees.
2. PAN cause injury in beets, celery, pepper, aster and promise. It causes silvering of leaves and death to forest trees.
3. PAN inhibits important **Hill reaction** of photosynthesis.
- ✓ 4. Smog is regarded to produce early maturity in plants.

6. Exposure of 4 ppb of PAN for 4 hours is known to create visible damage in plants. Vegetation damage may take several forms such as chlorosis, leaf abscission and curling etc.
6. Photochemical smog alone or in conjunction with  $O_3$ , PAN and  $NO_3$  cause damage to forest, agriculture and other materials like rubber, paint, fibers and polymers.
7. Both ozone and peroxy acyl nitrate (PAN) cause irritation of the eyes creating lacrimation and affect severely the respiratory tract of human beings. Exposure to 50 ppm of  $O_3$  for several hours will lead to mortality due to pulmonary edema, i.e., accumulation of blood in the lungs.
8. Primary photochemical pollutant i.e.,  $NO_2$  produces a brownish haze causing nose and eye irritation and pulmonary discomfort.
9.  $NO_x$  also cause several chronic diseases of heart, lungs and eyes.
10. Lower concentration of ozone irritates the nose and throat while its higher concentration causes headache, cough dryness of the throat, chest pain, difficulty in breathing etc.
11. The exposure of ozone upto 0.3 ppm appears to be the threshold level at which nose and throat irritation begins.
12. Exposure to ozone concentration of 1.0 to 3.0 ppm for a period of two hours produces extreme fatigue and lack of coordination in central nervous system.
13. Aromatic hydrocarbons which are conductive to smog formation are much more irritating to the mucous membranes and their inhalation causes systematic injury to the trachea.

#### *Effects of Photochemical Oxidants on Plants*

1. Ozone injuries to plants are bleached or light flecks or stipules (clusters of dead cells) on the upper surface of leaves. Fully expanded, mature leaves are more susceptible to damage. Leaves tip burn a disease of white pines is mainly caused by ozone.
2. Smog which contains  $O_3$ , PAN and other photochemical oxidants is regarded to produce early maturity or senescence in plants.
3. Exposure of smog even at a very low concentration of 0.01 ppm is reported to cause injuries to petunia, lettuce and pinto bean, citrus, forge and salad crops and coniferous trees.
4. PAN causes injury in beets, spinach, celery, pepper, lettuce, alfalfa, aster and primrose etc.
5. PAN also causes silvering of leaves  $NO_x$  and PAN cause death to forest trees.
6. Ozone promotes excessive transpiration from the leaves of plants causing dehydration.
7. All these pollutants also destroy the cells of leaves damage the shoots and interfere with blanketing the sunshine which inhibits the rate of photosynthesis in plants.
8. Ozone is also harmful for vegetables such as radish, carrot, tobacco and carnation.
9. Some sulphates and nitrates which are formed during smog formation due to the oxidation of sulphur containing components ( $SO_2$  and  $H_2S$ ) and  $NO_x$  ( $N_2O_3$ ,  $N_2C_5$ ,

$\text{NO}_2$ ) nitric acid and some nitrates are important toxicants of smog. They adversely affect plant growth, damage crops and live stock.

#### *Effects of Photochemical Oxidants on Materials*

1. The smoke containing fog, dust, mist and soot etc. in the smog reduces the visibility and causes corrosion of metals, stones,
2. causes corrosion of building materials,
3. causes corrosion of textile, paper, rubber, leather and painted surfaces.
4. Many organic polymers including rubber, natural and synthetic textiles are subjected to chemical alteration upon exposure to varying quantities of ozone.

#### *Control of Photochemical Pollutants*

1. The control of primary precursors such as  $\text{NO}_x$  and hydrocarbons will ultimately control ozone and PAN which are secondary pollutants.
2. Now days the techniques, like incineration absorption, adsorption and condensation are devised to control hydrocarbons emissions from stationary sources.

##### **(1) Incineration method**

Hydrocarbons removal efficiencies are greater in **flame after burner** in which flame is used to complete the oxidation of hydrocarbons into carbon dioxide and water. The other device makes the use of catalytic after burner in which the catalyst oxidises the hydrocarbon at a lower temperature. The efficiency and fuel cost are lower in this type of incinerator. Catalyst may also cause poisoning during the reaction.

##### **(2) Adsorption method**

In this method, polluted gases are passed through a bed of granulated absorber consisting of activated carbon. Hydrocarbon vapours are absorbed on the surface of activated carbon which remain there until they are periodically removed by passing stream through the system. The hydrocarbons are then condensed to liquids and can be used for further purpose.

##### **(3) Absorption method**

When the gases are passed on the bed of liquid scrubber then hydrocarbon gets absorbed on liquid or trapped in the scrubbing liquid.

##### **(4) Condensation method**

In this process smog forming pollutants to condense to liquids, which are collected and reused. on the other hand, the control of hydrocarbons emissions coming out from automobiles is more, complicated. The use of oxidising catalyst would convert CO and hydrocarbons to  $\text{CO}_2$  and water while a reducing catalyst would convert  $\text{NO}_x$  to  $\text{N}_2$ .