INTRODUCTION

The term environment is derived from the French word **Environner** which means surroundings and it is considered as a composite term for the conditions in which organisms live. Environment (Protection) Act, 1986 defined **environment as the sum total of water, air and land, their inter-relationships among themselves and with the human beings, other living beings and property**. Environmentalists defined environment as the mother of natural resources—energy, land, water, atmosphere and minerals. Protecting our precious environment is every one's concern in the fast developing world.

ENVIRONMENTAL SEGMENTS

The environment consists of four segments *viz.*, lithosphere, hydrosphere, atmosphere and biosphere.

1. Lithosphere.

The mantle of rocks constituting the earth's crust is called lithosphere. The **soil** covering the rocks (which results from physical, chemical and biological processes during weathering) is the important part of lithosphere. The soil mainly consists of complex mixture of inorganic and organic matter, minerals, air and water. The inorganic mineral constituents include complex mixture of silicates of Na, K, Ca, Al and Fe, oxides of Fe, Mn and Ti and carbonates of Ca and Mg. The organic matter, which is only 5%, mainly determines the productivity of the soil. It consists of biologically active components such as polysaccharides, organo-sulphur and organo-phosphorus, nucleotides, sugars and humic materials. The clay minerals and humus present in soil possess a very high cation exchange capacity and help in supplying essential trace metals to the plants as nutrients. The cations in the soil are exchanged for H^+ from the carbonic acid present in the soil and thus supply the trace metals to the plants through the roots. Thus *soil is a store house of minerals, reservoir of water, conserver of soil fertility, producer of crops, home of wild life and livestock.*

2. Hydrosphere.

Hydrosphere includes all the surface and ground water resources *viz.*, rivers, seas, oceans, streams, lakes, reservoirs, glaciers, polar ice caps, waters locked in rock-crevices and minerals lying deep below the earth crust. Earth is called the **blue planet** because about 80% of its surface is covered by water. However, 97% of the earth's water resources is locked-up in seas and oceans, which is too saline to drink and for the direct use for industrial and agricultural purposes. Of the remaining 3%, about 2·3% is trapped in giant glaciers and polar ice-caps. Thus not even 1% of the total world's water resources is available for exploitation by man for domestic, agriculture and industrial purposes. Water is an excellent universal solvent. It exhibits unusual properties due to the presence of hydrogen bonding. Water is a polar molecule. It has a density $1 g/cm^3$, surface tension 73 dynes per cm at 20°C, viscosity 0·01 poise at 20°C, dielectric constant 82, m.p. 0°C and b.p. 100°C at atmospheric pressure. Natural water contains ions such as Na^+, K^+, Mg^{2+}, Cl^-, SO_4^{2-}, PO_4^{3-}, NO_3^-, CO_3^{2-} and HCO_3^- etc.

3. Biosphere.

Biosphere is the region of earth where life exists and includes a global girdle extending from about 10,000 m below sea level to 600 m above sea level. Thus the biosphere covers the entire realm of living organisms and their interaction with the environment *viz.*, atmosphere, lithosphere and hydrosphere. Both the biosphere and environment are influenced considerably by each other. The oxygen and carbon dioxide levels of the atmosphere depend entirely on plant kingdom. The biological world, in general, is intimately related with energy flows in the environment and water chemistry.

4. Atmosphere.

The atmosphere is the **protective blanket of gases** surrounding the earth which sustains life on earth and saves it from the hostile environment of outer space. It absorbs most of the cosmic rays from outer space and a major portion of electromagnetic radiation from the sun. The atmosphere screens the dangerous ultraviolet radiations from the sun (< 300 nm) and transmits only near ultraviolet, visible, near infra red radiations (300 to 2500 nm) and radio-waves ($0 \cdot 01$ to 4×10^5 nm). The atmosphere comprises of a mixture of gases like N_2, O_2, CO_2, Ar etc. and extends upto about 500 kms above the earth surface. A constant exchange of matter takes place between the atmosphere, biosphere and hydrosphere. Their relative weights are of the following order.

1 (Biosphere) : 300 (Atmosphere) : 69100 (Hydrosphere).

The weight of atmosphere is nearly 5×10^{15} metric tonnes which is about one millionth of the total weight of the earth. The atmospheric temperature, pressure and density vary considerably with altitude. Thus atmospheric temperature varies from –100°C to +1200°C depending upon the altitude. The atmospheric pressure at sea-level is 1 atmosphere, while at 100 km above sea level, it drops to 3×10^{-7} atmosphere. Its density at the surface of earth is about $0 \cdot 0013$ g per cubic metre which decreases sharply with increasing altitude and gradually thins out into space. At about 600 km and above, the atoms and molecules describe free elliptical orbits in the earth's gravitational field.

The atmosphere plays a vital role in maintaining the **heat balance** on the earth by absorbing the infra red radiations received from the sun and re-emitted by the earth. In fact, it is the **green house effect** which keeps the earth warm enough to sustain life on the earth. The important gaseous constituents of the earth such as O_2, N_2, CO_2 play important roles in sustaining life on earth. O_2 supports life on earth. **Nitrogen** is an essential macro-nutrient for plants (*via* N_2-fixation and fertilizer manufacture). CO_2 is essential for photosynthetic activity of plants. Moreover, atmosphere is a carrier of water from oceans to land, which is so vital for the hydrological cycle. Any major disturbance in the atmospheric composition, either by natural or anthropogenic activities, may lead to disastrous consequences and may endanger the very survival of life on the earth.

COMPOSITION OF THE ATMOSPHERE

The composition of clean, dry air, near sea-level in given in Table 1.1.

Table 1.1. Composition of clean, dry air, near sea-level

Components	*Content*	
	per cent by volume	*ppm*
(a) Major components		
Nitrogen (N_2)	78.09	7,80,900
Oxygen (O_2)	20.94	2,09,400
Water Vapour (H_2O)	0.1-5	1,000-50,000
(b) Minor Components		
Argon (Ar)	0.934	9,340
Carbon dioxide (CO_2)	0.032	320
(c) Trace Components		
Neon (Ne)	0.00182	18.2
Helium (He)	0.000524	5.24
Methane (CH_4)	0.00018	1.8
Krypton (Kr)	0.00011	1.1
Nitrous oxide (N_2O)	0.000025	0.25
Hydrogen (H_2)	0.00005	0.5
Xenon (Xe)	0.0000087	0.087
Sulphur dioxide (SO_2)	0.0000002	0.002
Nitrogen dioxide (NO_2)	0.0000001	0.001
Ammonia (NH_3)	0.000001	0.01
Carbon monoxide (CO)	0.000012	0.12
Ozone (O_3)	0.000002	0.02
Iodine (I_2)	Traces	Traces

Table 1.2. Characteristics of the major regions of the atmosphere

Name of the region	Height above the earth's surface, km.	Temperature range °C	Major chemical species present
Troposphere	0 – 11	15 to – 56	O_2, N_2, CO_2, H_2O
Stratosphere	11 – 50	– 56 to – 2	O_3
Mesosphere	50 – 85	– 2 to – 92	O^+_2, NO^+
Thermosphere	85 – 500	–92 to 1200	O^+_2, O^+, NO^+

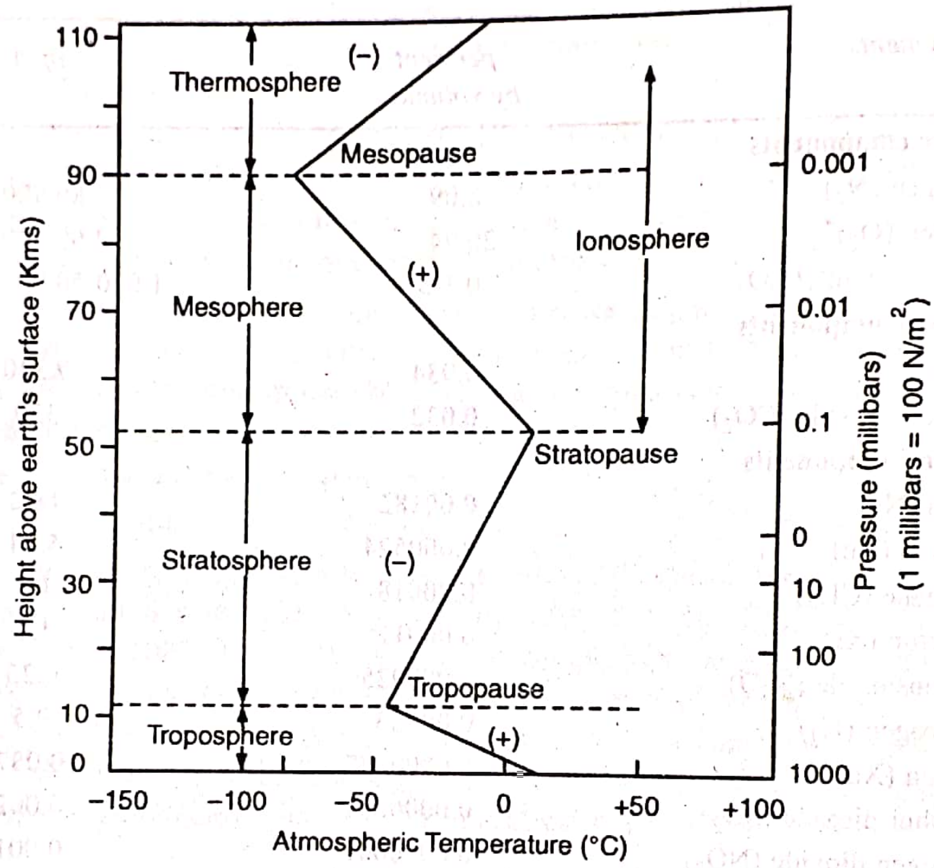

Fig. 1. Major atmospheric regions with temperature and pressure profile.

(1) Troposphere. This is the region nearest to the earth's surface and extends upto an altitude of 11 km. The upper limit may vary by a few kilometers, depending upon temperature, nature of the terrestrial surface and some other factors. The troposphere acounts for over 70% of the atmospheric mass. The composition of air in this region remains more or less constant in the absence of any significant air pollution. This is mostly due to the turbulence and constant circulation of air masses, as a result of convection currents arising from differential heating and cooling rates between the equator and the poles. The density of air, in this region, decreases exponentially with increasing altitude. The troposphere contains most of the water, cloud and particulate matter of the atmosphere.

The temperature of air in the troposphere decreases fairly steadily with increasing altitude from the ground temperature to a temperature of about –56°C. It can be seen from Fig. 1 that the temperature-altitude curve then changes its slope (*i.e.*, the temperature starts increasing with increasing altitude) rather suddenly in a narrow transitional layer at the top of the troposphere, known as the "Tropopause", which is usually at an altitude of 10 km to 20 km. The temperature of the tropopause is the least at the equator.

The change of temperature with height is called the "lapse rate". The decrease of temperature with increasing altitude in the troposphere is called positive lapse rate. The transition from positive lapse rate to negative lapse rate at the tropopause marks what is called the "temperature inversion".

(2) Stratosphere. The region above the tropopause is called the stratosphere. In this region, the temperature-altitude curve shows a warming trend with increasing altitude *i.e.*, it exhibits a negative lapse-rate. The temperature in this stratospheric region continues to increase with height, until 50 kms, where the temperature attains a maximum of –2°C. This warming up tendency in the stratosphere is due to the absorption of solar *u.v.* radiation by ozone, whose concentration in this region is in the range of 1 to 5 ppm by volume and this is responsible for the negative lapse-rate. The air in this region is very dry and the clouds and convection currents from the troposphere normally do not penetrate into it.

The presence of ozone in the stratosphere serves as a shield to protect life on the earth from the harmful effects of the solar *u.v.* radiations. Moreover, it serves as a source of heat for separating the quiescent stratosphere from the turbulent troposphere.

Because of the quiescent nature of the stratosphere, the molecules and particles in the region have long residence times. This is significant from the point of view of atmospheric pollution because any pollutant reaching this region may spell long term global hazard, as compared to their impact in the troposphere, which is much denser and more turbulent.

The region immediately above the stratosphere (above 50 km height) is called "Stratopause" which is the second transitional layer that is relatively warm. This is not much coller than the earth's surface. It reflects sound waves from earth back to the surface.

(3) Mesosphere. This is the region above the "Stratopause" and extends upto 85 km height. In this region, the temperature again decreases with height *i.e*, it exhibits a positive lapse-rate. This is due to relatively low levels of ozone and other species that can absorb *u.v.* radiations from the sun. The temperature, at the top of the Mesosphere, reaches about –92°C. Immediately above the Mesophere is another transitional layer, called "Mesopause" which is the region of minimum or coldest temperature in the atmosphere (*i.e*, about –100°C)

(4) Thermosphere. This is the region immediately above the mesopause, where the temperature rises very rapidly with increasing altitude, exhibiting a negative lapse-rate. The maximum temperature that is attained in this region is about 1200°C. This region is characterised by low pressures and low densities. The atmospheric gases present in this region (e.g., oxygen and nitric oxide) absorb the solar radiations in the far ultra-violet region and undergo ionisation.

The region above the stratosphere, in the altitude range of 50 km to 100 km, is called "Ionosphere". In this region, positive ions e.g., O_2^+, O^+, NO^+ etc and electrons exists at significant levels. These charged species persist for long periods of time, without mutual neutralization, due to the rarefied conditions existing in the region.

The troposphere, the stratosphere and the mesosphere are fairly uniform in composition. From air pollution point of view, troposphere is of particular significance.

5. Anthrosphere.

It consists of things humans construct, use and do in the environment. The anthrosphere constitute the fifth sphere of the environment along with the geosphere, hydrosphere, atmosphere and biosphere.

HEAT/RADIATION BUDGET OF THE EARTH

The earth continuously receives energy from the sun, a part of which is absorbed, while the remaining is emitted back into space. The earth maintains its heat balance within narrow limits, due to complex mechanism of energy transfer. Hence, optimum conditions are maintained for supporting life. The sun radiates energy, like a black body at 6000 K. Out of the solar radiations reaching the earth, 92% consists of radiations in the range 315 to 1400 nm. 45% of this lies in the visible region, *i.e.*, 400 to 700 nm. The earth absorbs radiations in the visible region and emits in the infra red region (2 to 40 μ with maximum at 10 μ).

Solar constant (S) is the quantity of solar energy per unit time passing through unit area at right angles to the direction of solar beam measured just outside the earth's atmosphere. The **solar flux** that is, the total energy reaching the earth's upper atmosphere is 1340 watts m^{-2} min^{-1}. The heat equivalent of the solar radiation reaching the earth is estimated to be $2 \cdot 68 \times 10^{24}$ joules per year.

However, only a portion of this energy can actually be absorbed at earth's surface. Of the total **solar flux,** a portion (31%) is reflected back into space and **does not contribute** to the energy budget of the earth. **Total reflectivity** of the earth is **31 units,** that is 6 units reflected from the earth's surface, 17 units due to clouds and 8 units by aerosols. This is known as **earth's albedo** in percentage terms, as 31% (or $A = 0 \cdot 31$). Of the non reflecting **69 units** of solar energy, 4 units are absorbed and thus retained within the earth's atmosphere by water droplets in the clouds and 19 units are absorbed by other aerosols and gaseous species such as ozone. Thus 4 + 19 = 23% of the solar energy reaching the earth is absorbed in the atmosphere while only $69 - 23 = 46\%$ is actually absorbed by land or water.

Mechanism.

Energy transport plays a crucial role in the earth's heat/radiation balance. This proceeds through the mechanism of

(i) Conduction of energy through the interaction of atoms or molecules.

(ii) Convection of energy through massive air circulation.

(iii) Radiation of energy in the infra red region (2 to 40 μ).

(iv) Re-absorption of most of the outgoing infra red radiation by water vapour (4 to 8 μ and above 13 μ), CH_4 (3 to 4 μ in the window region), O_3 (9 to 10 μ), N_2O (3 to 5 μ and 7 to 9 μ), CO_2 (14 to 19 μ and it completely blocks the radiative flux between 15 to 16 μ) and re-emitting a part of this radiation to earth.

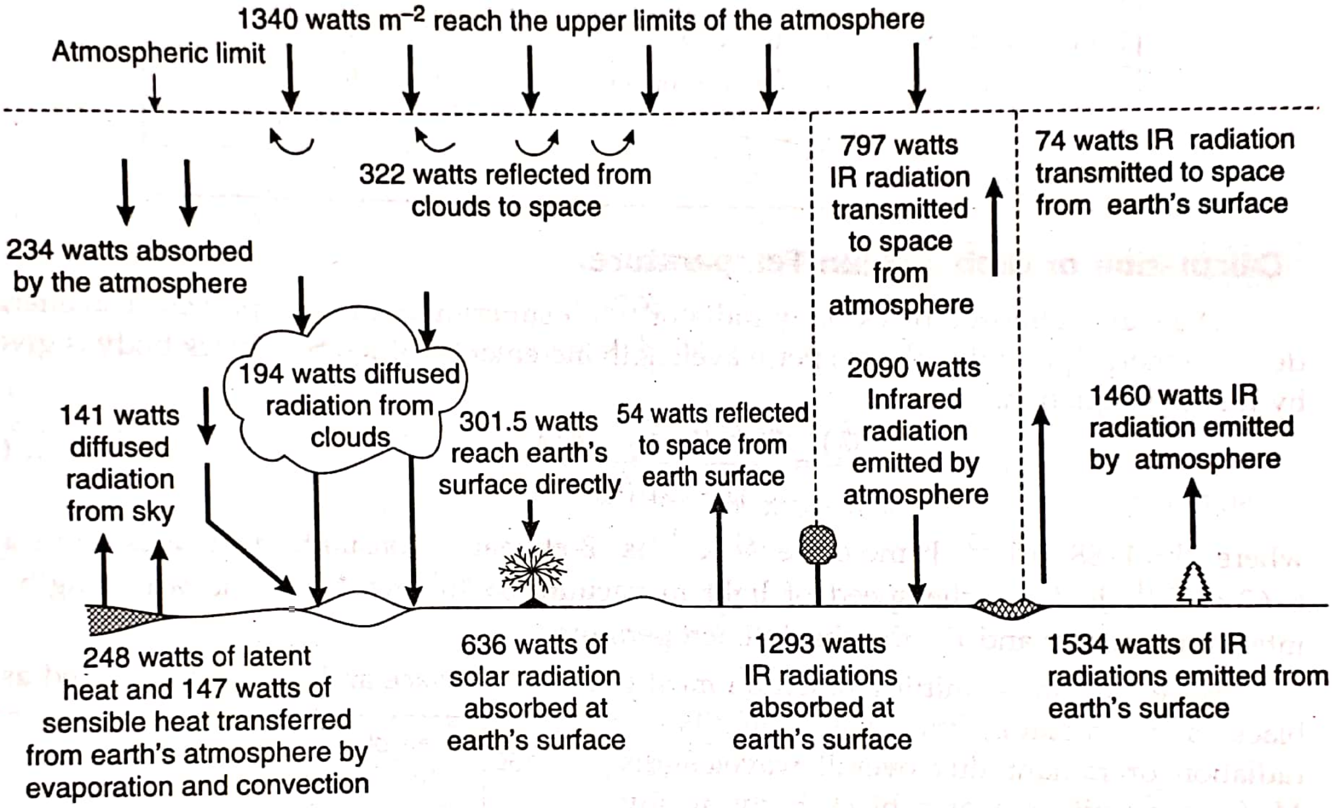

Fig. 2. Earth's radiation budget expressed on the basis of portions of the 1340 watts m^{-2} composing the solar flux.

The combined effect of water vapour, CO_2, CH_4, O_3, N_2O and CFCs lead to the **green house effect** which is of great significance in governing the climate on earth. Increasing **agricultural and industrial outputs** can also upset the earth's radiation balance by changing the **albedo** (fraction of sunlight reflected and scattered back to the atmosphere). Deforestation and the consequent soil erosion increase the albedo. Further, the particulate matter in the atmosphere, which is released by **natural forces** (wind, sea sprays and volcanoes) or by anthropogenic activities (*e.g.*, agricultural and industrial activities which release dust, fumes, smoke, soot) also exert cooling or heating effect depending upon the nature of the particles which may reflect, scatter or absorb radiations.

BIODISTRIBUTION OF ELEMENTS

Natural environmental cycles operating in earth's environment have significant links which are mainly controlled by micro-organisms. The micro-organisms mediate processes within all the nutrient cycles, act as catalysts and transform many inorganic and organic species. The aquatic and terrestrial behaviour of C, N, and S is regulated largely by microbial activities. Micro-organisms lead to the formation of many sediments and mineral deposits. Algae are considered as primary producers of biological organic matter (biomass) in aquatic ecosystem. Algae utilise sunlight and store it as chemical energy. In absence of sunlight, algae use the stored chemical energy for metabolic requirements and serve as **aquatic solar fuel cells.**

Consider major abiotic and biotic processes on land and water. Carbon cycle is one of the most important cycles that determines the forms of life and their interaction within the global environment. Every organic compound and all the inorganic carbonate species fit into the carbon cycle in some way through synthesis, transformation and decomposition. The main **reservoirs** of carbon in the terrestrial environment are :

(i) Carbonate rocks, limestone and dolomite.

(ii) The organic material in the soil.

(iii) Material buried in the earth (fossil fuel) as solid coal, liquid petroleum and natural gas. Thus fossil fuel and soil organic matter are of biological origin.

Carbonate species are present in all natural waters arising from atmospheric CO_2 and remineralised organic matter. The oceans are large reservoirs of carbon compounds that plays an important role in maintaining the global carbon balance. **Photoautotrophic** micro-organisms synthesize organic matter using inorganic carbonate species from both water and air as their carbon source. The additional carbonate is incorporated micro-biologically to form hard structures of some oceanic plankton. This **carbon assimilation** slightly raises the pH of surface water and lowers the alkalinity below **thermocline.** The carbonate shells sink into the deeper parts of the ocean where there is no solar flux. The biological decomposition of organic matter produces carbon and CO_2, thereby causing a decrease in pH through the thermocline.

Another process in carbon cycle which is controlled by microbial activity is decomposition of **biomass.** The biomass is mainly composed of cellulose. The oxidation of biomass by molecular oxygen liberates CO_2. In the absence of oxygen, it is also possible to degrade organic matter via other oxidation reactions. The nitrate can act as an electron acceptor, being reduced to nitrite, ammonium ions, nitrous oxide or nitrogen depending on environmental conditions. When oxygen and nitrate ions are absent and sulphate ions are present the latter may act as an electron acceptor for the oxidation of organic matter. In oxygen depleted organic rich marine sediments, **Desulphovibrio bacteria** enhance oxidation processes.

However, in absence of oxygen, sulphate or nitrate species of actinomycetes causes **anaerobic biodegradation** (fermentation) liberating methane. Any species in a water body (*e.g.*, NH_4^+, S^{2-}, reduced forms of Fe, Mn, Cr etc.) that can react with dissolved oxygen contributes to **biological oxygen demand** (BOD) and create anoxic conditions. Degradation of biomass is not only the microbial process controlling dissolved oxygen content of water bodies but living microbes, especially algae also affect oxygen levels. The cycle can be explained in terms of chemical reactions corresponding to photosynthesis and respiration.

$$CO_2 + H_2O \underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} CH_2O + O_2$$

Almost all the life depends on chlorophyll and photosynthesis and food stuffs are either parts of plants or animals which feed on plants.

$$6CO_2 + 6H_2O \xrightarrow{\text{Sunlight}} C_6H_{12}O_6 + 6O_2$$

Green plants, brown and blue green algae through photosynthesis remove about 360 billion tonnes of CO_2 from the atmosphere per year. Same amount of CO_2 is returned to the atmosphere either by respiration or by death and putrefaction of plant or animal remains.

Nitrogen cycle involves nature's most vital dynamic processes. Here nitrogen enters the air by the activities of **denitrifying bacteria** and returning to the cycle through the action of **nitrogen fixing bacteria** or blue green algae and also by lightning. There is continuous turnover of nitrogen between the atmosphere, the soil and the sea living organisms. Combined nitrogen in the soil is present as nitrates, nitrites and ammonium compounds.

Losses of combined nitrogen from the soil take place due to following reasons.

(i) Plants absorb nitrogeneous compounds which are consumed by animals. Animals excrete nitrogeneous waste such as urea and uric acid which are returned to the soil. Death and decay eventually return almost all the nitrogen to the soil.

(ii) Denitrifying bacteria, called **denitrificans** convert nitrates into N_2 and NH_3 which escape into the atmosphere. NH_3 returns to the soil by first rain fall.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO_2 \rightarrow N_2 \rightarrow NH_3$$

(iii) The drainage of surface water into the sea causes a net loss of N_2 compounds in the soil. In sea, it supports marine plant life.

(iv) There is a little loss of NO_2 and NO into the atmosphere from the burning of plants, coal and from vehicular exhausts. This may produce smog locally, but the N_2 is returned to the soil when it rains.

Net gains of combined nitrogen in soil are due to following activities.

(i) One of the largest gains is from nitrifying bacteria which fix N_2 and convert it into nitrates and ammonium salts. **Rhizobium** bacteria live symbiotically in the nodules of **pisum sativum.** Other nitrifying bacteria *e.g.*, Anabaena, Nostoc, Azobacter, Clostridium require traces of metals such as Fe, Co, Cu, Zn, Mo and B from the soil. Nitrogenase reduces N_2, N_2O, N_3^-, RCN to NH_3. Nitrogen is believed to form a complex with Mo-Fe protein.

(ii) Lightning may cause N_2 and O_2 in the air to form NO and NO_2. The strong UV radiations in the upper atmosphere may cause similar photochemical changes.

The process of **nitrogen fixation** is followed by **nitrification, denitrification, decomposition, leaching, run off and rainout.** N_2 fixation requires energy to break the strong N≡N bond which is provided by lightning and cosmic rays. The bond energy for N≡N bond is 945 kJ mol^{-1}. The conversion of nitrogen from organic to inorganic forms is a type of mineralisation, called **ammonification.** The NH_4^+ ions undergo oxidation in an aerobic environment. Nitrification mediated by Rhizobium bacteria depends on pH.

$$3[CH_2O] + 2N_2 + 3H_2O + 4H^+ \xrightarrow{\text{Rhizobium}} 3CO_2 + 4NH_4^+$$

$$2NH_4^+(aq) + 3O_2 + 2H_2O \xrightarrow{\text{Nitrosomonas}} 2NO_2^-(aq) + 4H_3O^+(aq)$$

$$2NO_2^-(aq) + O_2 + H_2O \xrightarrow{\text{Nitrobacter}} 2NO_3^-(aq)$$

Net reaction is $$NH_4^+(aq) + 2O_2 + H_2O \longrightarrow NO_3^-(aq) + 2H_3O^+(aq)$$

After C, H and O the N is the important element required by plants and microbes for their growth in soil and water. Nitrate is readily leached through soil into surface or ground water. The maximum permissible limit of nitrate in water is between 10 to 50 mg L^{-1}. **Escherichia coli** bacteria convert NO_3^- to NO_2^- which reacts with haemoglobin causing oxygen deficiency. Nitrites also react with secondary amines and amides to form carcinogenic *N*-nitrosoamines. Excessive level of NO_3^- causes **eutrophication in water.**

In Oxygen cycle the balance between O_2 and CO_2 is maintained by green plants and animals through photosynthesis and respiration. [For details Refer to Oxygen Cycle.]

Sulphur cycle **constitutes** sulphur as an essential nutrient for plants and micro-organisms. Mineral forms of sulphur include FeS_2 and $CaSO_4$ (gypsum). Sulphur exists in organic matter in both **carbon bonded and oxygen bonded forms.** The carbon bonded organic sulphur is present as a component of protein in the form of amino acid **cysteine.** It is mineralised by desulphydrase. For oxygen bonded organic sulphur, microbial mineralisation involves hydrolytic decomposition of S—O bond via **sulphatase enzymes.**

$$HS{-}CH_2{-}\underset{\displaystyle COOH}{\overset{\displaystyle NH_2}{CH}} + H_2O \xrightarrow[\text{Desulphohydrase}]{\text{Cysteine}} CH_3COCOOH + HS^-(aq) + NH_4^+(aq)$$

$$RO\,SO_2O^-(aq) + 2H_2O \xrightarrow{\text{Sulphatase}} ROH + SO_4^{2-}(aq) + H_3O^+(aq)$$

The sulphide is unstable under aerobic conditions. It is oxidised in presence of chemoautotrophic bacteria such as thiobacillus thio-oxidants. These bacteria occur in water, sediments and soil. They also multiply rapidly when supplied with a source of sulphide.

$$HS^-(aq) + 2O_2 + H_2O \longrightarrow SO_4^{2-}(aq) + H_3O^+(aq)$$

Sulphate is reduced to HS^- or S by **Desulphovibrio** desulphurican's bacteria.

$$SO_4^{2-}(aq) + 2CH_2O + H_3O^+(aq) \longrightarrow HS^-(aq) + 2CO_2 + 3H_2O$$

$$2SO_4^{2-}(aq) + 3CH_2O + 4H_3O^+(aq) \longrightarrow 2S + 3CO_2 + 9H_2O$$

The generated sulphide species (HS^- or H_2S) are toxic to aquatic life.

Phosphorus cycle operate in environment as PO_4^{3-}, H_2PO_4, HPO_4^- or soluble inorganic or organic phosphate or as mineral phosphate. Terrestrial plants absorb inorganic phosphate salts from the soil and convert these into organic phosphate. Animals obtain their phosphate by consuming plants. Plants and animals after their death and decay return phosphates to the soil, which are finally converted to humus by soil micro-organisms. The sedimentary phase of phosphorus cycle remains slower than the organic phase.

Biogeochemical cycles involve biodistribution of elements that are essential to life. Cu, Zn, Cr, Ca, Mn etc. are the abundant elements that make up the **sedimentary cycle. Copper,** an essential chalcophile, is ubiquitous in earth crust as sulphide. It is required as trace element for both plants and animals but its excess amount is toxic. Copper is necessary for normal biological activities of amine oxidase and tyrosinase enzymes.

Copper has the ability to form complexes with ligands having nitrogen donor atom. At **low pH,** the aquo complex of copper is the main species in neutral fresh water which is in equilibrium with the atmosphere. At **higher pH,** deprotonation from HCO_3^- occurs and a complex containing two CO_3^{2-} ions is formed.

Copper also forms complexes with dissolved humic material and a fraction of nitrogen present in it binds with copper forming a stable species. But the solubility of copper is increased if humic substances are present in dissolved form. However, suspended or precipitated humic material serves to remove soluble copper from the aquatic system.

Zinc, an essential trace element, occurs as 0·004% in earth crust (ZnS, $ZnCO_3$) and 20 ppb in oceans. Several zinc enzymes act as catalyst for RNA and DNA metabolism.

Chromium is distributed in the earth crust at about 200 ppm level and in sea water at 3 ppb. In nature, Cr occurs as chromium iron ore, $FeO \cdot Cr_2O_3$. Its trace amounts are essential to man but higher levels are toxic.

Calcium is one of the most abundant element that makes up the **sedimentary cycle.** About 7% of the total sedimentary material flowing down the rivers is calcium. For every 1000 atoms of Ca, 2·4 atoms of Sr move to the sea. Tiny amounts of Sr–90 have now followed calcium from soil and water into vegetation, animals and human food. In soils, Ca is the principal ion occupying exchange sites on the organic and mineral material. But this exchangeable Ca is readily displaced by acidity in water passing through the soil.

Calcium occurs as limestone, dolomite, alumino silicate minerals (feldspar) and clay mineral montmorillonite. Calcium interacts with dissolved humic material and act as essential constituent for plants. Micro-organisms such as Ferrobacillus, Gallionella, Sphaerotilus utilise iron compounds to drive energy for their metabolic processes. They serve as catalysts for the oxidation of Fe(II) to Fe(III) by O_2.

$$4Fe^{2+} + 4H^+ + O_2 \longrightarrow 4Fe^{3+} + 2H_2O$$

Gallionella secrete larger quantities of hydrated Fe_2O_3 *i.e.*, $Fe_2O_3 \cdot 3H_2O$ or $2Fe(OH)_3$.

The **manganese cycle** in the ocean is strongly influenced by bacteria. The manganese nodules, an important source of Mn, Cu and Co give different species of bacteria which mediate both the oxidation and reduction of Mn. The reactions are governed by enzymes and sea water cations such as Ca^{2+} and Mg^{2+}.

The non-essential elements which circulate between organisms and environment are also involved in **sedimentary cycle.** Radioactive Sr–90 behaves like calcium and combine with blood making tissues, which is susceptible to radiation damage. Sr–90 has two gaseous precursors ($Kr^{90} \rightarrow Rb^{90} \rightarrow Sr^{90}$). Cs–137 behaves like potassium and is absorbed by organisms.

Methylated **mercury** CH_3Hg^+ is produced in sediments by a number of microbiological processes. CH_3Hg^+ forms complexes such as CH_3HgCl and $(CH_3Hg)_2S$ with a variety of ligands. These species are toxic both to fish and animals including man which may consume fish. Methylated derivatives of tin (IV) and lead (IV) have been detected in natural waters. **Arsenic** has also a biological cycle. Alkyl arsenic compounds accumulate in shell fish. Arsenic occurs in rocks and soils from where it may enter the water bodies. Arsenic is held tightly in soil and is not readily leached. **Zinc and cadmium** can not be methylated. Thallium and palladium can also be methylated like mercury.