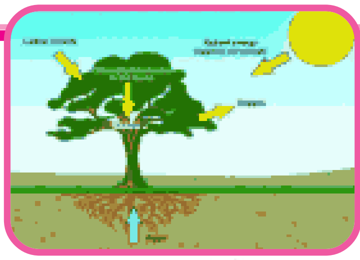
Chapter 11

Bio geo chemical cycles



We have learnt about environmental pollution and ecosystem in the previous chapter. Living things within an ecosystem interact with each other and also with their non-living environment to form an ecological unit that is largely self-contained. Sometimes this renewal process is gradual and gentle. Sometimes it is violent and destructive. Nevertheless, ecosystems contain resources within themselves which can regenerate.

There is usually a physical state, chemical form, and location in the cycle in which nature stores the bulk of the various chemical elements. Pollution occurs when the cycle is sufficiently disturbed either by accumulation of any element at some point in the cycle in inappropriate physical state or chemical form or amount disrupting environmental balance.

Thus, this is important to understand how nature is maintaining itself and what are the impacts of human activities on this self contained ecological unit. To understand these, we would need to know atleast some of the cycles of nature in which nutrients are exchanged and passed on from one level to the other as well as from one state to the other. The cycles that involve the flow of nutrients in on earth (elements essential for the living cell) from environment to organisms and back through certain pathways are known as biogeochemical cycles.

Biogeochemical cycles

A constant interaction, between the biotic and abiotic components of the biosphere, makes it a dynamic, but stable system. These interactions consist of transfer of matter and energy between the different components of the biosphere. Biogeochemical pathways determine the path of transfer of matter on earth. Let us look at some of the major biogeochemical cycles.

Biogeochemical cycles as we may see from the name itself includes both biological , geological and chemical or physicochemical pathways. This means the reservoir or pool of nutrients on earth may contain some chemicals of biological origin while others may be purely inorganic in nature also may be geochemical (obtained from rocks and soil) in origin.

Water though not considered as a biogeochemical cycle by most ecologists actually is the precursor of the major elements hydrogen and oxygen as some living organisms use them for making the basic food molecules for several organisms in nature.

Water is also a universal solvent and essential for various reations to take place within a living cell. Thus we shall also take up water cycle briefly in this chapter. Though the nutrient pool involves several elements of nature but, we shall study just the cycling of some major elements like oxygen, nitrogen and carbon.

The water cycle

All of the water that is on the earth has always been here. Earth never gets water added to it nor does water disappear from the earth. Water is constantly recycled in a process known as the hydrological or water cycle.

Fresh water is more scarce than you might think. Nearly 97% of all the water on the earth is in the oceans, and so only about 3% is fresh water. About 2% of this fresh water is permanently frozen in glaciers and at the polar ice caps.

Thus only about 1% is available fresh water. Again about 1/4 of this 1% is present as groundwater. Only about 0.009% of water on earth is in the rivers and lakes. Rest is present in the bodies of living organisms, as soil moisture, as humidity of atmosphere etc. Water is the most essential, abundant substance in living things.

The human body for example, is composed of about 70% water (remember all living organisms together constitute only 0.005% of water on earth). Water participates in many biochemical mechanisms, including photosynthesis, digestion and cellular respiration. It is also the habitat for many species of plants, animals and microorganisms, and it participates in the cycling of the materials used by living things. So, it is important that we protect our water resources.

You have seen how water evaporates from the water bodies in the form of water vapour and the subsequent condensation of this water vapour leads to rain.

The whole process in which water evaporates and falls back on the surface of the earth as rain and other forms of precipitation including its flow from land into the sea/

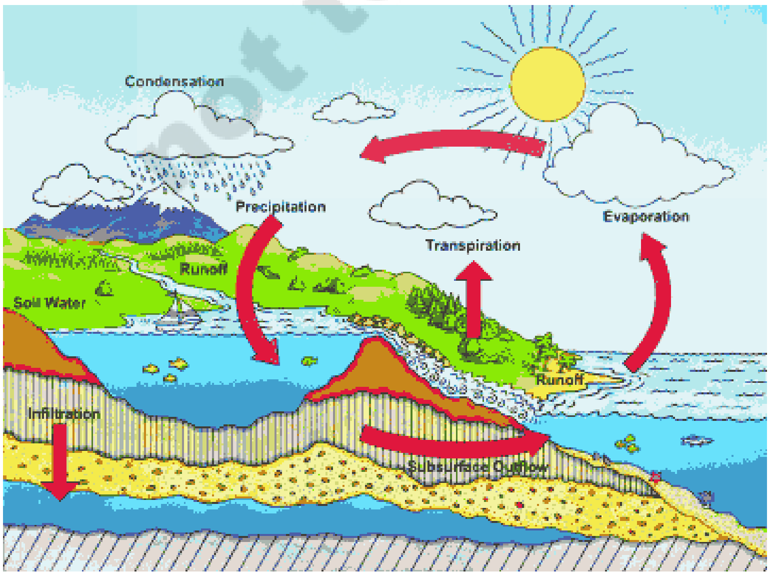


Fig-1 Water cycle

oceans via several routes like rivers, ground water channels etc is known as the water-cycle.

This cycle is not as straight-forward and simple as this statement seems to imply. All of the water that falls on the land does not immediately flow back into the sea. Some of it seeps into the soil and becomes part of the underground reservoir of fresh-water.

Some of this underground water finds its way to the surface through springs. Or we bring it to the surface for our use through wells or tube wells. Water is also used by terrestrial animals and plants for various life-processes. Water provides hydrogen and oxygen that form integral part of basic organic compounds of life.

Let us look at another aspect of what happens to water during the water-cycle. As you know, water is capable of dissolving a large number of substances. Thus, it cleans the environment as it rains and water soluble pollutants are transported to different water bodies like lakes and oceans.

This dilutes the intensity of pollutants Also, as water flows through or over rocks containing soluble minerals, some of them get dissolved in the water. Thus rivers carry many nutrients from the land to the sea, and some of these are used by the marine organisms and rest of these get deposited which takes a longer time to cycle completely through the system.

On the other hand, it creates troubles as well. Dissolution of some harmful substances, like gases like SO_2 and oxides of nitrogen in rain water leads to 'acid rain'.

The nitrogen cycle

Nitrogen is both the most abundant element in the atmosphere and, a building block of proteins and nucleic acids. The nitrogen cycle is a complex biogeochemical cycle in which nitrogen is converted from its inert atmospheric molecular form (N_2) into a form that is useful in biological processes.

The element Nitrogen is constantly moving in a giant circle from the air, through the soil, into the bodies of plants and animals, and eventually back to the air by the process of nitrogen cycle. All living things need nitrogen mainly for growth, repair and development (nitrogen being essential for protein formation). Even though the earth's atmosphere is made up of 78% nitrogen, plants and animals cannot use it in this form.

The atmospheric nitrogen is thus converted into certain compounds that plants may take up from the soil by some biochemical (caused by certain bacteria like Rhizobium, Nitrosomonas etc) and physicochemical (caused by lightning) processes. Animals get the required amount of nitrogen from plants either directly (herbivores) or indirectly (carnivores).

The nitrogen cycle contains several stages:

1. Nitrogen fixation

Atmospheric nitrogen occurs primarily in inert form (N_2) or non reactive form that few organisms can use; therefore it must be converted into a compound - or fixed - form in a process called nitrogen fixation. Most atmospheric nitrogen is 'fixed' through biological processes. A number of bacteria and blue green algae are known to be able to fix atmospheric nitrogen into compounds in their own body. These may be symbiotic (Rhizobium) or freeliving (Nitrosomonas) respectively. These organisms convert atmospheric nitrogen into the organic nitrogen for their own cells. As they die rapidly(they grow rapidly as well), this nitrogen, now present in the soil as compounds become available to plants. In leguminous plants like pea, beans etc there is a symbiotic relationship of the nitrogen fixing bacteria with the plant, thus nitrogenenous compounds are added to the soil after a leguminous crop is grown.

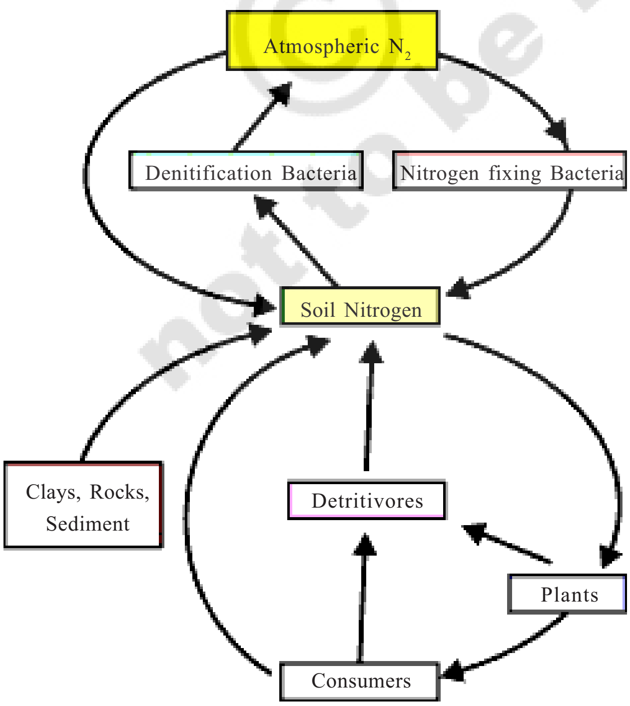


Fig-2 Nitrogen fixation

Nitrogen can also be fixed as nitrates by lightning. This reaches soil and water through precipitation that follows. Nitrates are taken up by plants to form proteins and nucleic acids.

2. Nitrification

Nitrates can also be converted to ammonia by the denitrifying bacteria in the soil (especially in waterlogged soils). The nitrifying bacteria may then use this ammonia to synthesize compounds for their own cell and eventually convert to proteins, nucleic acids, nitrites and nitrates. Nitrites are produced mainly by Nitrosomonas, while nitrates by Nitrobacters that are also capable of utilizing nitrites and converting them to nitrates. Death of these microorganisms add the nitrogenous compounds to the soil. Plants take up nitrate as well as ammonium ions from the soil to convert them to proteins and nucleic acids.

Nitrification can thus be summarized as:

Nitrates
↓ Denitrifying Bacteria
Ammonia
↓ Nitrosomonas
Nitrite
↓ Nitrobacter
Nitrate
↓
Plants

3. Assimilation

Nitrogen compounds mainly as nitrates or ammonium ions(NH_4^+) are taken up from soils by plants which are then used in the formation of plant proteins and as animals eat these plants, animal proteins are synthesised.

4.Ammonification

Production of ammonia (NH_3) from nitrates and other nitrogenous compounds in called ammonification.

- Describe a path of ammonification discussed in the above section.

Ammonification also occurs when plants and animals die, or when animals emit wastes, the nitrogen in the organi c matter reenters the soil and water bodies where it is broken down by other microorganisms, known as decomposers. This decomposition produces ammonia which is then available for other biological processes.

Note: Processes 2-4 also contribute to nitrogen fixation.

5.Denitrification

Nitrogen makes its way back into the atmosphere through a process called denitrification, in which solid nitrate (NO_3) is converted back to gaseous nitrogen (N_2). Denitrification occurs primarily in wet soils where water makes it difficult for microorganisms to get oxygen. Under these conditions, certain organisms - known as denitrifiying bacteria - will process nitrate to gain oxygen, leaving free nitrogen gas as a byproduct.

Thus, the nitrogen content of the earth and its atmosphere remains in a perfect balance.

Human intervention and nitrogen cycle

Unfortunately, humans are interfering with the natural balance when they overuse artificially produced nitrates as agricultural fertilizers that are often washed into water bodies by rain as well as by releasing exponential amounts of untreated domestic sewage into water bodies. Before these nitrates can be converted into atmospheric nitrogen, they are often carried off by rain or irrigation to streams and rivers and even seep down to groundwater.

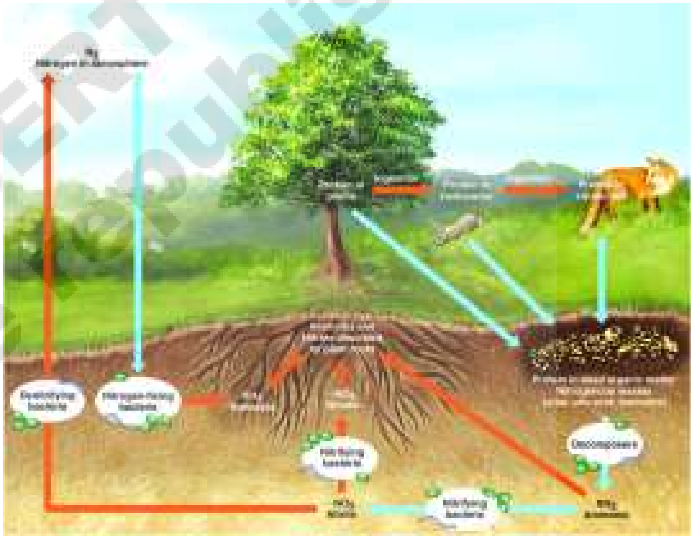


Fig-3

In some parts of the world, water for humans and animals contains such high concentrations of nitrates that it is unsafe for consumption. These excessive amount of nitrates and other nitrogenous compounds, when they reach rivers and lakes, cause too much algal growth. This over-abundance of algae uses up too much of the oxygen in the water. When oxygen level falls, other forms of life in the water bodies die off.

These were just a few examples of human intervention.

The carbon cycle

Carbon is found in various forms on the Earth. It occurs in the elemental form as say soot, diamond and graphite. In the combined state, it is found as gases, carbon dioxide and carbon monoxide in the atmosphere, as carbonate and hydrogen carbonate salts in various minerals, while all life-forms are composed of carbon containing molecules like proteins, carbohydrates, fats, nucleic acids and vitamins. The endoskeletons and exoskeletons of various animals are also formed from carbonate salts.

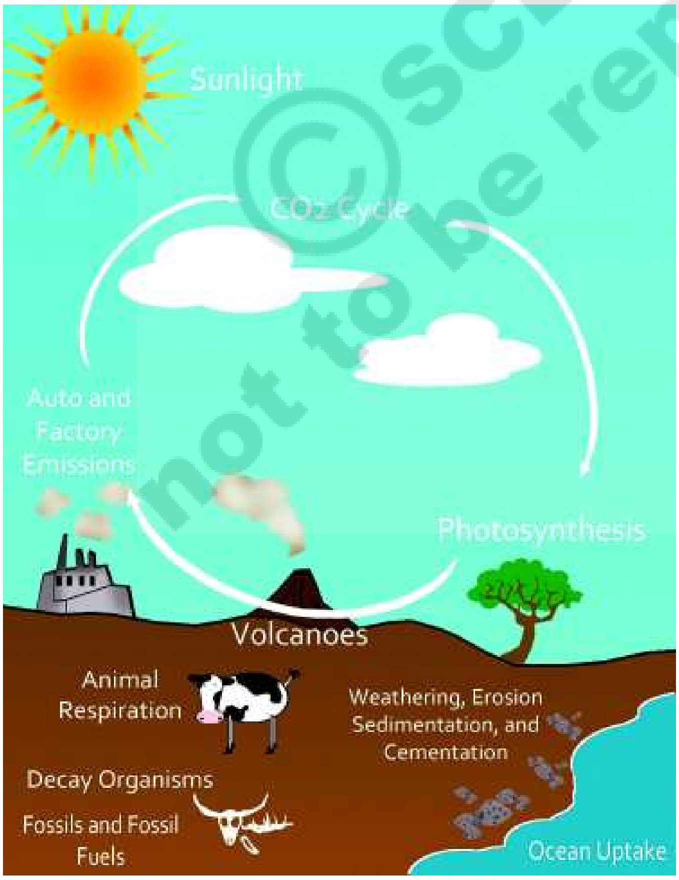


Fig-4 Carban cycle

Carbon dioxide is also responsible for maintaining the Earth as a greenhouse with temperature conditions suitable for life. Thus, carbon exists in the biosphere as the central element of life. Carbon Dioxide or CO_2, now makes up about 0.04% by volume of air.

Have you ever thought how this level of carbon is being maintained in the nature?

Carbon is incorporated into life through various processes. The main reservoirs of carbon are sedimentary rocks, fossilized organic carbon including the fossil fuels, the oceans, and the biosphere.

Photosynthesis

The first step in the biological carbon cycle is the conversion of inorganic atmospheric carbon into a biological form. This 'fixing' of carbon in biological form takes place within plants and other organisms - known as producers - in a process called photosynthesis, by which energy from sunlight is converted into chemical form.

In photosynthesis, light energy helps to combine carbon dioxide and water to create the simplest of sugars, the carbohydrate molecules known as glucose ($C_6H_{12}O_6$). In oceans, photosynthesis is carried out by microscopic aquatic plants called phytoplankton. The carbohydrates then become the source of chemical energy that fuel living cells in all plants and animals. In plants, some carbon remains as simple glucose for

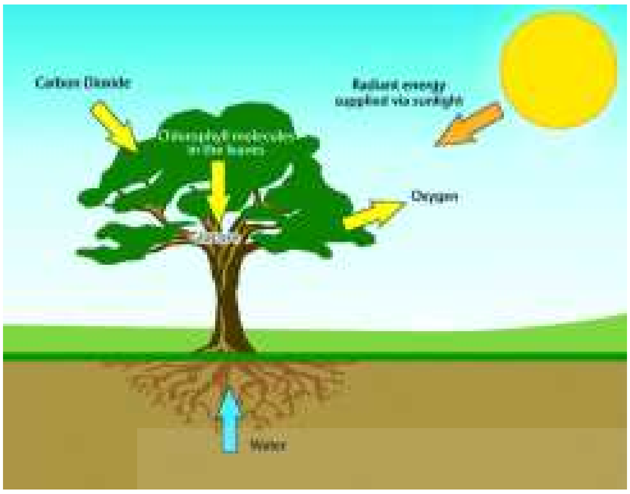


Fig-5

short-term energy use, while some are converted to large complex molecules such as starch for longer term energy storage.

Cycling and storage

The movement of carbondioxide takes place from the atmospheric reservoir of carbon dioxide directly as such to producers mainly the green plants, to consumers and from both of these groups to the microbial decomposer organisms. Fossil fuels, carbonate rocks and carbondioxide dissolved in the oceans are major additional reservoirs of carbon.

The first two of these additional reservoir are not directly available to plants for fixation. CO_2 from these resources becomes available when either fossil fuels are burnt or insoluble carbonates are converted to soluble bicarbonates. The return of carbondioxide to the atmospheric reservoir is accomplished in many ways.

Mainly through respiratory processes wherein food molecules are broken down for energy and CO_2 gas and other byproducts are emitted. Combustion of fossil fuels and other carbon containing substances, forest fires, volcanic emissions etc. also return carbondioxide to the atmospheric reservoir.

Other pathways are like- When a plant dies, it is broken down by microorganisms - called decomposers - that feed on the dead organic matter. As the microorganisms consume the plant matter, they release some of the plant's carbon into the atmosphere in the form of CO_2, although some is destined for longer-term storage in trunks and branches of trees and in the bodies of plant-eating animals or carnivorous animals that eat plant-eating animals.

Animals return more of the carbon to the atmosphere as CO_2 through respiration as we already know, although some will be stored within their bodies until they die and decompose in the soil. Carbon in the form of several compounds will remain stored in the soil as organic matter for example the fossil fuels that we use.

Carbon cycle and human intervention

Carbon buried under the ocean floor might take millions of years to return to the atmosphere, if it does at all. Throughout the Earth's history, the emission of CO_2 (and many other gases) from deep below the planet's surface happens as geological events, such as volcanic eruptions. A large part of the atmospheric carbon dioxide that we have today was contributed by such geological events of the past.

Human beings tap into the geological carbon cycle by extracting oil and coal, which are both hydrocarbons(formed of carbon and hydrogen), for use in automobiles and power plants. A by product of combustion of these hydrocarbons is CO_2 and CO gases. Since the Industrial Revolution began, carbon dioxide levels in the atmosphere have increased measurably, mostly as a result of human use of fossil fuels.

Humans have also altered the biological carbon cycle, increasing atmospheric CO_2 levels, through forest clearing and land use. Trees store large amounts of carbon; when they die and decompose, much of this stored carbon is released as CO_2.

However, when humans clear large Places of forest, primarily through the use of fire, the levels of atmospheric carbon are affected in two ways. First, during combustion, stored carbon is released directly into the air as CO_2, and second, the clearing of land takes away a key mechanism for removing excess carbon dioxide from the atmosphere (via photosynthesis).

Since carbon dioxide is a primary greenhouse gas, the increase in atmospheric CO_2 due to human activities has resulted in an enhanced greenhouse effect resulting in higher global temperatures.

The green house effect

A greenhouse is a small house made of glass that is used to grow plants. It traps the sun's rays and keeps the heat from escaping. It is warm inside. In the same way that the glass traps heat in a greenhouse, some gases present in the atmosphere such as carbon dioxide, carbon monoxide, methane and water vapour trap heat from radiating back to the space. The natural greenhouse gases act like a big blanket around the earth, keeping it warm and

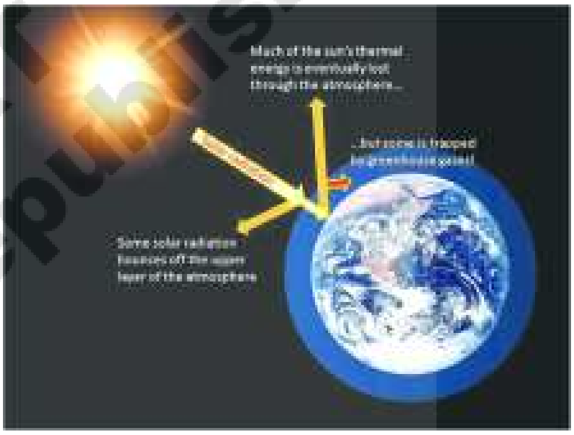


Fig-6 Green house effect

making life possible without which temperatures would have fallen to sub zero values.This phenomenon of naturally warming up is called "Greenhouse effect".

But the extent of this natural warming up process have been grossly affected now. Due to various human activities like burning of fossil fuels, deforestation and industrialization, an excessive amount of carbon dioxide and other green house gases has been emitted to the environment. As a result more heat gets trapped. This causes the temperature of the earth to rise, which results in Global Warming. Global

Fig-7 Green house gases

Warming is the recorded increase in the average temperatures of the earth's atmosphere and oceans. Global Warming affects the weather patterns on Earth and causes Climate Change. Climate change results in higher sea levels, more rainfall and severe droughts and floods.

What effect does climate change have on humans and animals? Discuss and write in your note book.

Lab Activity

Aim: Test the effect of a greenhouse on temperature

Materials required: Plastic bottle, nail, 2 thermometers, notebook and pencil.

Procedure: Make a hole near the top of the plastic bottle with the nail. Insert the first thermometer into the hole. Place the second thermometer next to the bottle. Make sure that the same amount of sunlight reaches both thermometers. After 10 minutes, note temperature values from both thermometers. Record the data in the notebook. Take the temperature records again after another 10 minutes and repeat it for 2-3 times more.

Now, answer the following questions:

Do both thermometers record the same temperature? If no, which one is higher?

Can you explain why these two temperature records are not the same?

Oxygen cycle

Oxygen is an abundant element, next to Nitrogen, on our Earth. It is found in the elemental form in the atmosphere to the extent of nearly 21%. It also occurs extensively in the combined form in the Earth's crust as well as in the air in the form of carbon dioxide. In the crust, it is found as the oxides of most metals. It is also present as carbonate, sulphate, nitrate and other compounds. It is also an essential component of most biological molecules like carbohydrates, proteins, nucleic acids and fats (or lipids).

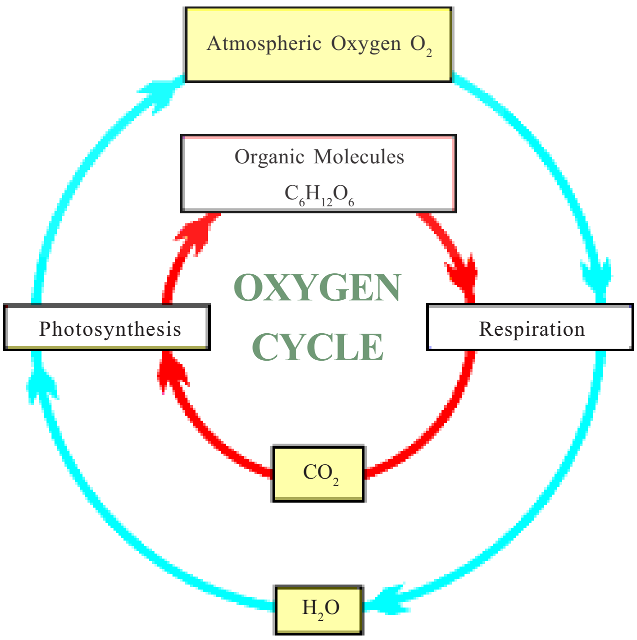


Fig-8 Oxygen cycle

Do you Know?

Though we usually think of oxygen as being necessary to life in the process of respiration, it might be of interest to you to learn that some forms of life, especially bacteria, are poisoned by elemental oxygen. In fact, even the process of nitrogen-fixing by bacteria does not take place in the presence of oxygen.

Oxygen is vital for life in many ways. Respiration utilizes oxygen releasing carbon dioxide to atmospheric pool maintaining a balance in nature. Dissolved oxygen supports aquatic life. Oxygen dissolves in water on the basis of different conditions. High temperatures do not support the process while a lot of turbulence in water usually at the surface helps greater amount of oxygen to dissolve.

Oxygen is needed for the decomposition of organic waste. Wastes from living organisms are "biodegradable" because there are aerobic bacteria that convert organic waste materials into stable inorganic materials. If enough oxygen is not available for these bacteria, for example, because of enormous quantities of wastes, they die and anaerobic bacteria that do not need oxygen take over. These bacteria change waste material into H_2S and other poisonous and foul-smelling substances.

The content of biodegradable substances in water is expressed by a special index called "biological oxygen demand" (BOD), representing the amount of oxygen needed by aerobic bacteria to decompose the waste. As the wastes get degraded and the dissolved oxygen is used up proportionately, the need or demand for oxygen increases i.e. the BOD increases. Thus BOD is a good indirect indicator for amount of biodegradable waste.

The cycle and storage

Oxygen from the atmosphere is used up mainly by the processes, combustion, respiration and in the formation of oxides of elements like nitrogen, iron etc. Oxygen is returned to the atmosphere in only one major process, that is, photosynthesis.

Ozone layer

The Earth's atmosphere is divided into several layers. The lowest region, the troposphere, extends from the Earth's surface up to about 10 kilometers (km) in altitude. Virtually all human activities occur in the troposphere. Mt. Everest, the tallest mountain on the planet, is only about 9 km

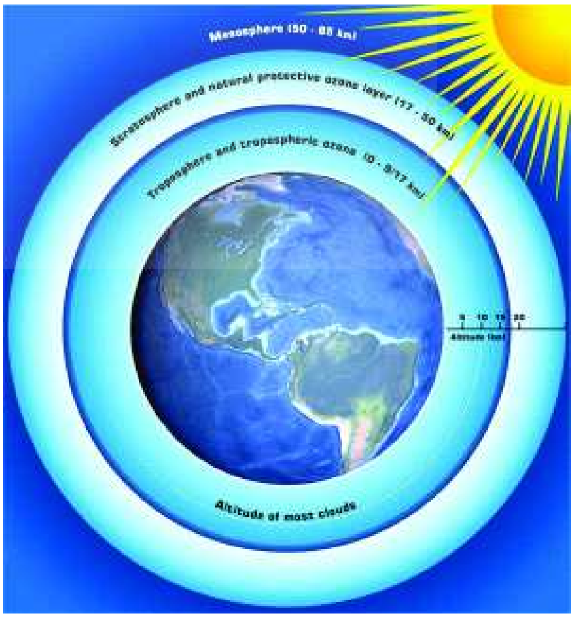


Fig-9 Ozone layer

high. The next layer, the stratosphere, continues from 10 km to about 50 km. Most commercial airline traffic occurs in the lower part of the stratosphere. most atmospheric ozone is concentrated in a layer in the stratosphere, about 15-30 kilometers above the Earth's surface. Ozone is a molecule containing three oxygen atoms. It is blue in color and has a strong odor.

Normal oxygen, which we breathe, has two oxygen atoms and is colorless and odorless. Ozone is much less common than normal oxygen. Out of each 10 million air molecules, about 2 million are normal oxygen, but only 3 out of 10 millions are ozone.

However, even the small amount of ozone plays a key role in the atmosphere. The ozone layer absorbs a portion of the radiation from the sun, preventing it from reaching the planet's surface.

Most important of all it absorbs the portion of ultraviolet light which causes many harmful effects, including various types of skin cancer and harm to some crops, certain materials, and some forms of marine life.

At any given time, ozone molecules constantly get formed and destroyed in the stratosphere. The total amount, however, remains relatively constant.

Ozone depletion

Certain industrial processes and consumer products result in the emission of ozone-depleting substances to the atmosphere. These gases bring chlorine and

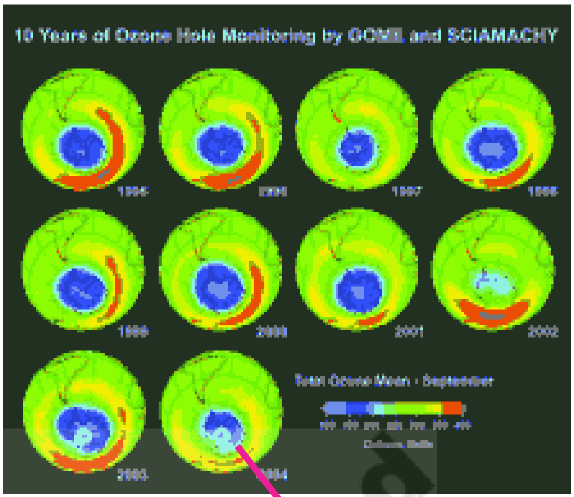
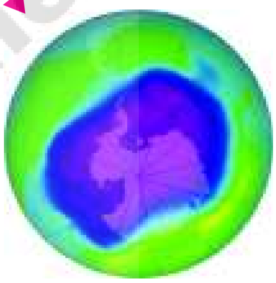


Fig-10 Ozone depletion



fluorine atoms to the stratosphere, where they destroy ozone in chemical reactions. Important examples are the chlorofluorocarbons (CFCs), used in almost all refrigeration and air conditioning systems. Most of these gases accumulate in the lower atmosphere because they are unreactive and do not dissolve readily in rain or snow. Natural air motions transport these accumulated gases to the stratosphere, where they are converted to more reactive gases. Some of these gases then participate in reactions that destroy ozone. The ozone hole is not really a hole, but it was observed that there is less ozone in Antarctica than in the arctic region.

Montreal protocol

The discovery of an ozone hole over Antarctica prompted action to control the use of gases which have a destructive effect on the *ozone layer*. From this concern emerged the Montreal Protocol on substances that deplete the ozone layer, signed by 24 countries in 1987. It came into force in 1989 and has since been ratified by 120 countries. The original agreement was to control and phase out the production and supply of ozone depleting chemicals, specifically CFCs (*chlorofluorocarbons*) and their derivatives. A meeting in 1992 was held in Copenhagen to revise the Protocol. This meeting agreed to bring forward the phase out of *halons* to 1994, and CFCs and other *halocarbons* to 1996. These targets have since been met.

Key words

Water Cycle or hydrologic Cycle, Nitrogen Cycle, Nitrogen Fixation, Nitrification, Assimilation, Ammonification, Denitrification, Carbon Cycle, Greenhouse Effect, Global warming, Oxygen Cycle, Ozone Depletion.

What we have learnt?

- Representations of biological, geological and chemical processes that involve the movement of an element or compound about the surface of the earth are collectively known as 'Biogeochemical cycles'.
- Living things within an ecosystem interact with each other and also with their non-living environment to form an ecological unit that is largely self-contained.
- Ecosystems contain within themselves the resources to regenerate themselves and there is usually a physical state, chemical form and location in the cycle in which nature stores the bulk of various chemical elements.
- Biogeochemical cycles are complex in nature and consist of pools of several elements (like carbon, oxygen, nitrogen, phosphorous, calcium, potassium, sodium, iron etc) essential for life that circulate through living systems and are replenished in the pool. They include a variety of biological, geological and chemical processes.
- Water, oxygen, carbon and nitrogen are the key elements for life and are continuously recycled in the nature.
- Denitrification is the conversion, principally by bacteria, of compounds of nitrogen in soil and aquatic systems to the gases, nitrogen (N_2) and nitrous oxide (N_2O) and eventual release of these into the atmosphere.

- Biological oxygen demand is an indicator of amount of biodegradable waste in an ecosystem.
- The warming of the Earth's atmosphere and surface by the atmospheric greenhouse gases such as Carbon dioxide, methane and water vapors is called 'greenhouse effect'.
- Nitrification is the process of the conversion of ammonium to nitrite and nitrate by bacteria.
- Nitrogen fixation is the conversion of atmospheric nitrogen gas into ammonium and nitrates. Fixation may take place due to lightning and bacteria (into nitrates and into ammonium ions)
- A substance that supplies nutrition to a living organism, like carbohydrates, fats, proteins, vitamins, salts, iron, calcium, phosphorus etc are called nutrients.

Improve your learning

1. What is the importance of different biogeochemical cycles in the nature? (AS1)
2. What do you understand by Ozone layer? Write an essay to participate in elecution compitation on importance of ozone layer. (AS 6)
3. What emissions from human activities lead to ozone depletion? And what are the principal steps in stratospheric ozone depletion caused by human activities? (AS1)
4. Why could we say that biogeochemical cycles are in "balance"? (AS1)
5. What role does carbon dioxide play in plant life processes? (AS 7)
6. If all the vegetation in the pond died, what effects would it have on the animals? Why? (AS 2)
7. Burning of fossil fuels a concern for scientists and environmentalists, why? (AS 6)
8. How human activities caused an imbalance in biogeochemical cycles? (AS 7)
9. List three ways we, as humans, have affected the water cycle.(AS 7)
10. Describe interdependence of biotic and abiotic components by taking Nitrogen cycle as an example.Draw Nitrogen Cycle. (AS 5)
11. Go to a nearby pond observe organisms living in the pond and bio degradable substances mixing in water. How they effect on those organisms? write your observation.(AS4)
12. Prepare slogans on Green house Effect to announce in your school assembly (AS 7)