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I. Environmental Chemistry

By Dr. Dejene Ayele Tessema

II. Prerequisite Courses or Knowledge

Before taking this course students should revise the following units from their introductory chemistry course.

- Gas laws and properties
- Solutions and concentration units
- Chemical Equilibrium
- Ionic Equilibrium
- Acid base reactions and equilibrium

III. Time required for each unit

Unit I. The Environment (25 hrs)
Unit II. Atmospheric chemistry and Air pollution (35 hrs)
Unit III. Aquatic chemistry and Water pollution (35 hrs)
Unit IV. Soil Chemistry and Pollution (25 hrs)

IV. Materials

For all the units in this module students require,

- Computer with internet facility to access links and relevant copy write free-resources.
- CD-Rom accompanying this module for supplemental readings and to check answers to the exercises given in each of the learning activities.

V. Module Rationale

What is the course about?

Massive amounts of chemicals produced by modern industries have given humankind an unprecedented standard of living and quality of life. However, this has also exerted a price of environmental degradation. To make a contribution to the improvement of environmental quality, individuals need to have some knowledge of environmental chemistry. Chemistry teachers are then expected to know and pass environmental knowledge to the society via their students.
The overall goal of this course is to gain an understanding of the fundamental chemical processes that are central to a range of important environmental problems and to utilize this knowledge in making critical evaluations of these problems. Specific goals include:

- An understanding of the chemistry of the stratospheric ozone layer and of the important ozone depletion processes.
- An understanding of the chemistry of important tropospheric processes, including photochemical smog and acid precipitation.
- An understanding of the basic physics of the greenhouse effect and of the sources and sinks of the family of greenhouse gases.
- An understanding of the nature, reactivity, and environmental fates of toxic organic chemicals.
- An understanding of societal implications of some environmental problems

**VI. Content**

**6.1 Module Overview**

In general this module applies the fundamental principles of chemistry to gain an understanding of the source, fate, and reactivity of compounds in natural and polluted environments. The first unit discusses and familiarizes students with the various divisions of the environment and explains the possible consequences of the overuse of natural resources to foster an appreciation of the catastrophic consequences of negligent human act. In the following units emphasis is given to the hydrosphere, atmosphere, and soils. Environmental issues that will be discussed include atmospheric layers and the chemical reactions taking place in the atmosphere; ozone depletion; atmospheric pollutants and their sources; global warming and acid rain; climate change; water and its special properties; chemical reactions taking place in water bodies; water pollution and sources of pollutants; soil – its formation, characteristics, and pollution.

**6.2 Module Outline**

*Unit I  The Environment (25 hrs)*

- Introduction
- Natural Resources Consumption
- Population Increase and the Environment
- Urbanization and the environment
- Industrialization and the Environment
Unit II  Atmospheric chemistry and Air pollution (35 hrs)

Atmospheric Chemistry
- Introduction
- Earth’s Atmosphere
- Temperature and the Atmospheric layers
- Characteristics of the Major Regions of the Atmosphere
- Atmospheric Chemical Reactions

Air Pollution,
- Classification of Air Pollutants,
- Major Sources of Air Pollutants,
- Air Pollution and Acid-Rain,
- Air Pollution and Ozone Depletion,
- Global Warming,
- Solving the Problem

Unit III  Aquatic chemistry and Water pollution (35 hrs)

Aquatic Chemistry
- Properties of water
- Chemical Reactions in Water Bodies
- Dissolved gases in water
- Acid-base phenomena in water
- Complexation Reactions in Water

Water Pollution
- Water Quality
- Nature and types of water pollutants
- Characterization of Waste Waters
- Water Pollution Control
- Water quality requirements

Unit IV  Soil Chemistry and Pollution (25 hrs)

Soil Chemistry
- Introduction
- Composition of Soils
- Soil Formation
- Soil Characteristics
- Soil Classification
- Soil Erosion
Soil Pollution

- Sources of Soil Pollution
- Effects of Soil Pollution
- Control of Soil Pollution

6.3 Graphic Organizer

VII. General Objective

This course is about environmental issues and the chemistry behind them. It aims to apply knowledge of chemistry to understand environmental issues. The goal of this course is to provide you the knowledge of how to do a chemist's share in improving environmental quality.
## VIII. Specific Learning Objectives

<table>
<thead>
<tr>
<th>Unit</th>
<th>Learning objective(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The Environment</td>
<td>Familiarize students with the various divisions of the environment and explain the possible consequences of the overuse of natural resources to foster an appreciation of the catastrophic consequences of negligent human act.</td>
</tr>
<tr>
<td>2. Atmospheric chemistry and Air pollution</td>
<td>Explain the gaseous components of the environment, the vertical variation in atmospheric temperature and the chemistry responsible for the observed variation, processes such as; ozone depletion, greenhouse effect, global warming.</td>
</tr>
<tr>
<td>3. Aquatic chemistry and Water pollution</td>
<td>To provide a fundamental understanding of the organic and inorganic chemical processes controlling the chemical composition of the aquatic environment and the fate of pollutants in the aquatic environment.</td>
</tr>
<tr>
<td>4. Soil Chemistry and Pollution</td>
<td>Familiarize students with the main constituents of soils and the way they are formed. Introduce some important characteristics of soils, their classification and the various ways in which soils are polluted.</td>
</tr>
</tbody>
</table>
IX. Teaching And Learning Activities

9.1 Pre-assessment

Title

Pre-assessment test for Environmental Chemistry course.

Rationale

This test is intended to assess the level of your existing chemistry knowledge, which is a prerequisite for successful learning of this module.

Questions

1. A solution contains 15 g sucrose (table sugar) and 60 g of water. What is the mass/mass % of the sucrose solution?
   a) 20%     b) 2%     c) 0.2%     d) 5%

2. What is the molarity of a solution made when water is added to 11 g CaCl₂ to make 100 mL of solution?
   a) 0.1 M       b) 0.01 M         c) 11.0 M       d) 1.0 M

3. A solution has a [H₃O⁺] of 1 x 10⁻⁵. What is the [OH⁻] of the solution?
   a) 1.0 x 10⁻⁻      b) 1.0 x 10⁻⁻⁸   c) 1.0 x 10⁻⁻⁹    d) 1.0 x 10⁻⁻⁷

4. An ammonia solution has a [OH⁻] of 1 x 10⁻³. What is the pH of the ammonia solution?
   a) 8                 b) 11               c) 3             d) 1.0 x 10⁻⁻¹⁻¹

5. That part of the Earth upon which humans live and from which they extract most of their food, minerals, and fuels is known as
   a) environment     b) geosphere   c) atmosphere    d) biosphere
6. The process by which plants fix solar energy and carbon from atmospheric CO\textsubscript{2} in the form of high-energy biomass, represented as \{CH\textsubscript{2}O\}, is known as
   a) fixation       b) solar-carbonation       c) transpiration       d) photosynthesis

7. When a mixture of gases is in contact with a liquid surface, the solubility of a given gas in the liquid
   a) is proportional to the temperature of the liquid
   b) is proportional to the partial pressure of that gas in contact with the liquid.
   c) is proportional to the total pressure exerted by the mixture of gases.
   d) none

8. Which is a gaseous product formed from the complete combustion of a fossil fuel?
   a) carbon dioxide       b) carbon monoxide       c) carbon       d) nitrogen

9. Which gas in the atmosphere most contributes to global warming?
   a) Hydrogen       b) nitrogen       c) carbon dioxide       d) carbon monoxide

10. Which of these causes a reduction in the ozone layer?
    a) increased burning of fossil fuels
    b) increased photochemical smog in cities
    c) increased sea temperature due to global warming
    d) increase in the use of chemicals in refrigerators and aerosol cans

11. Which most likely provides evidence of global warming?
    a) increased drought in parts of Africa
    b) increased ice sheet area at the South Pole
    c) thinner growth rings in trees in Northern Europe
    d) decreased fish stocks of the Atlantic Ocean

12. The air quality standard for carbon monoxide (based on an 8 hr measurement) is 9 ppm. When this standard is expressed in mg/m\textsuperscript{3} at 1 atm and 25\degree C its value is
    a) 0.01 mg/m\textsuperscript{3}       b) 37 mg/m\textsuperscript{3}       c) 0.009 mg/m\textsuperscript{3}       d) 10.3 mg/m\textsuperscript{3}
13. Earth’s atmosphere is a layer of gases surrounding the planet Earth and retained by the Earth’s gravity. Which of the following gases is the largest in proportion?
   a) oxygen       b) nitrogen,      c) hydrogen     d) carbon dioxide,

14. The solubility of calcium carbonate can be calculated as follows:

   \[ \text{CaCO}_3(s) \xrightarrow{K_e} \text{Ca}^{2+} + \text{CO}_3^{2-} \]

   The pH of CaCO$_3$ under equilibrium conditions in water, closed to the air = 9.95 and the [Ca$^{2+}$] = 1.26 x 10$^{-4}$, while when open to the air, pH = 8.40 and the [Ca$^{2+}$] = 3.98 x 10$^{-4}$. The reason for the observed increase in [Ca$^{2+}$] is
   a) dissolution of CaCO$_3$ by atmospheric CO$_2$ dissolved in the water.
   b) a shift in the equilibrium to the right due to an increase in pressure.
   c) a shift in the equilibrium to the right due to dissolution of atmospheric O$_2$.
   d) none

15. When moving from sea level to higher altitudes, atmospheric temperature
   a) is successively decreasing
   b) is successively increasing
   c) decreases and increases alternately
   d) remains constant

16. Which of the following is a reason for the concern over reduced stratospheric ozone concentrations?
   a) additional cancer due to additional UV radiation reaching the earth’s surface
   b) increased tropospheric ozone, which is a health risk to humans
   c) The effect of UV radiation reaching the earth’s surface on cyanobacteria, a bacteria on which a number of economically important plant species depend on for the retention of nitrogen.
   d) all

17. The overall cause of ozone depletion is associated with
   a) the presence of chlorofluorocarbons and related halocarbons serving as chlorine source gases.
   b) an increase in the green-house gases
   c) an increase in solar UV radiation
   d) the presence of oxides serving as oxygen sources
18. Water has a number of unique properties. One of these unique properties determines transfer of heat between the atmosphere and bodies of water. Which of the following is that property?
   a) Highest dielectric constant of any common liquid
   b) Higher heat of evaporation than any other material
   c) Maximum density as a liquid at 4°C
   d) Highest dielectric constant of any common liquid

19. Aldehydes are highly reactive molecules present in the environment that also can be produced during biotransformation of xenobiotics and endogenous metabolism. Which of the following molecular structures represents an aldehyde?

20. Bacterial degradation of waste water biomass, \{CH₂O\}, can be carried out either aerobically or anaerobically. Which of the following equations represents the anaerobic degradation of biomass?
   a) \( CH₂O + O₂ \rightarrow CO₂ + H₂O \)
   b) \( 2 CH₂O + O₂ \rightarrow CO₂ + CH₄ \)
   c) \( 2 CH₂O \rightarrow CO₂ + CH₄ \)
   d) \( CH₂O \rightarrow CO₂ + O₂ \)
**Answer Key**

1. a) 20%
2. d) 1.0 M
3. c) $1.0 \times 10^{-9}$
4. b) 11
5. b) geosphere
6. d) photosynthesis
7. b) is proportional to the partial pressure of that gas in contact with the liquid.
8. a) carbon dioxide
9. c) carbon dioxide
10. d) increase in the use of chemicals in refrigerators and aerosol cans
11. a) increased drought in parts of Africa
12. d) 10.3 mg/m³
13. b) nitrogen,
14. a) dissolution of CaCO₃ by atmospheric CO₂ dissolved in the water.
15. c) decreases and increases alternately
16. d) all
17. a) the presence of chlorofluorocarbons and related halocarbons serving as chlorine source gases.
18. b) Higher heat of evaporation than any other material

![Chemical Structure]

19. c)

20. c) $2 \text{CH}_2\text{O} \rightarrow \text{CO}_2 + \text{CH}_4$

**Pedagogical Comment For Learners**

Dear learner, the above pre-test is intended to test your knowledge on some concepts in general chemistry such as: concentration calculation, pH calculation, solubility and equilibrium, organic chemistry and some general concepts in environmental chemistry, which are mandatory for your understanding of this Environmental Chemistry course. If you score less than 50% in this test you are advised to revise the chapters mentioned before you proceed to the next chapter.
X. Learning Activity

Learning Activity 1

The environment

Summary of the Learning Activity

To provide the student a clear insight of the components of the environment, this learning activity presents an overview of the definition of the environment and the parts that constitute the environment. Ecological impacts of unwise use of the natural resources, the environmental impacts of industrialization, population growth and urbanization are also described.

At the end of this learning activity the student should be able to:

• Describe the various parts of the environment
• Discuss the environmental consequences of natural resources consumption
• Describe the environmental impacts of population increase and urbanization
• Discuss the influence of industrialization on environmental pollution

List of Relevant Readings


Manahan, Stanley E. “Environmental Science, Technology, and Chemistry”
Environmental Chemistry, 2000

List of Relevant resources

Computer with internet facility to access links and relevant copy write free resources.
CD-Rom accompanying this module for supplemental readings and to check the answers for the exercises given in the learning activity.
List of Useful Links


This link provides an overview of “environmental chemistry” in its broadest context: the chemical evolution and constitution of the lithosphere, hydrosphere, atmosphere, and biosphere.

1.1 Introduction

Unit I. The Environment (25 hrs)

- Introduction
- Natural Resources Consumption
- Population Increase and the Environment
- Urbanization and the environment
- Industrialization and the Environment

All the external factors that affect an organism could be defined as environment. These factors may be other living organisms or nonliving variables, such as water, soil, climate, light, and oxygen.

The environment is never static. Physical forces continuously change the surface of the earth through weather, the action of waves and natural phenomena such as volcanoes. At the same time they introduce gases, vapor and dust into the atmosphere. Living organisms also play a dynamic role through respiration, excretion and ultimately death and decay, recycling their constituent elements through the environment.

Just as the familiar substances of our physical universe are divided into solids, liquids and gases, for convenience our physical environment can be divided into the atmosphere, the geosphere, the hydrosphere, the biosphere, the anthroposphere, and all the fauna and flora. This is illustrated as follows using the various compartments of the environment as “separate” entities.
1.1.1 The Atmosphere

The atmosphere is the gaseous envelope that surrounds the solid body of the planet. Although it has a thickness of more than 1100 km about half its mass is concentrated in the lower 5.6 km.

The atmosphere:

- is a protective blanket which nurtures life on the Earth and protects it from the hostile environment of outer space.
- is the source of carbondioxide for plant photosynthesis and of oxygen for respiration.
- provides the nitrogen that nitrogen-fixing bacteria and ammonia-manufacturing industrial plants use to produce chemically-bound nitrogen, an essential component of life molecules.
- transports water from the oceans to land, thus acting as the condenser in a vast solar powered still.
- serves a vital protective function, absorbing harmful ultraviolet radiation from the sun and stabilizing Earth’s temperature.

1.1.2 The Hydrosphere

The hydrosphere is the layer of water that, in the form of the oceans, covers approximately 70.8 percent of the surface of the earth.

Water:

- covers about 70% of Earth’s surface and over 97 % of this water exists in oceans.
- occurs in all spheres of the environment—in the oceans as a vast reservoir of saltwater, on land as surface water in lakes and rivers, underground as groundwater, in the atmosphere as water vapor, in the polar icecaps as solid ice, and in many segments of the anthroposphere such as in boilers or municipal water distribution systems.
- is an essential part of all living systems and is the medium from which life evolved and in which life exists.
- carries energy and matter are through various spheres of the environment.
- leaches soluble constituents from mineral matter and carries them to the ocean or leaves them as mineral deposits some distance from their sources.
- carries plant nutrients from soil into the bodies of plants by way of plant roots.
- absorbs solar energy in oceans and this energy is carried as latent heat and released inland when it evaporates from oceans. The accompanying release of latent heat provides a large fraction of the energy that is transported from equatorial regions toward Earth’s poles and powers massive storms.
1.1.3 The Geosphere

The geosphere, is that part of the Earth upon which humans live and from which they extract most of their food, minerals, and fuels. It is divided into layers, which include the solid, iron-rich inner core, molten outer core, and the lithosphere - which consists of the upper mantle and the crust.

![Inner structure of the earth](image.png)

Environmental science is most concerned with the lithosphere.

- The lithosphere, extends to depths of 100 km and comprises two shells—the crust and upper mantle.
- The crust (the earth’s outer skin) is the layer that is accessible to humans and is extremely thin compared to the diameter of the earth, ranging from 5 to 40 km thick.

1.1.4 The Biosphere

The Biosphere is the earth’s relatively thin zone of air, soil, and water that is capable of supporting life, ranging from about 10 km into the atmosphere to the deepest ocean floor. Life in this zone depends on the sun’s energy and on the circulation of heat and essential nutrients.

The biosphere

- is virtually contained by the geosphere and hydrosphere in the very thin layer where these environmental spheres interface with the atmosphere.
- strongly influences, and in turn is strongly influenced by, the other parts of the environment.
- strongly influence bodies of water, producing biomass required for life in the water and mediating oxidation-reduction reactions in the water.
- is involved with weathering processes that break down rocks in the geosphere and convert rock matter to soil.
• is based upon plant photosynthesis, which fixes solar energy ($h\nu$) and carbon from atmospheric CO$_2$ in the form of high-energy biomass, represented as {CH$_2$O}:

$$CO_2 + H_2O \xrightarrow{h\nu} \{CH_2O\} + O_2(g)$$

### 1.1.5 The Anthroposphere

This is a name given to that part of the environment “made” or modified by humans and used for their activities. Of course, there are some ambiguities associated with this definition. Clearly, a factory building used for manufacturing is part of the anthroposphere, as is an ocean going ship used to ship goods made in the factory. The ocean on which the ship moves belongs to the hydrosphere, but it is clearly used by humans.

The anthroposphere

• is a strongly interconnection to the biosphere.
• has strongly influenced the biosphere and change it drastically. For example, destruction of wild life habitat has resulted in the extinction of vast numbers of species, in some cases even before they are discovered; bioengineering of organisms with recombinant DNA technology and older techniques of selection and hybridization are causing great changes in the characteristics of organisms and promise to result in even more striking alterations in the future.
• It is the responsibility of humankind to make such changes intelligently and to protect and nurture the biosphere.

### 1.1.6 The Flora and Fauna

The terms fauna and flora are collective names given to animals and plants respectively. There is a continuous interaction between the various sections of the environment and the flora and fauna. An assembly of mutually interacting organisms and their environment in which materials are interchanged in a largely cyclical manner is known as ecosystem. The environment in which a particular organism lives is called habitat.

We have thus far discussed the different parts of the atmosphere. Although for the convenience of our study we divided the environment into different sections, there exists an unbounded interaction between these parts. All parts of the environment are subjected to drastic change due to human overuse of natural resources.
1.2 Natural Resources Consumption

In the last two and half century, the industrial revolution has changed the face of the planet by natural resources at an alarming rate, especially fossil fuel. Every year natural resources consumption is rising as the human population increases and standards of living rise.

Following we shall discuss possible environmental consequences accompanying the over consumption of the natural resources: fossil fuel, forest wood, water, land and energy by humans.

1.2.1 Fossil Fuel

Fossil Fuels, which include petroleum, coal, and natural gas, are energy-rich substances that have formed from long-buried plants and microorganisms. They provide most of the energy that powers modern industrial society. The gasoline that fuels our cars, the coal that powers many electrical plants, and the natural gas that heats our homes are all fossil fuels.

Fossil fuels are largely composed of hydrocarbons which are formed from ancient living organisms that were buried under layers of sediment millions of years ago. These fuels are extracted from the earth’s crust, and refined into suitable fuel products, such as gasoline, heating oil, and kerosene. Some of these hydrocarbons may also be processed into plastics, chemicals, lubricants, and other non-fuel products. The most commonly used fossil fuels are petroleum, coal, and natural gas.

Once extracted and processed, fossil fuel can be burned for direct uses, such as to power cars or heat homes, or it can be combusted for the generation of electrical power.

What are the consequences?

Within the last century, the amount of carbon dioxide in the atmosphere has increased dramatically, largely because of the practice of burning fossil fuels. This has resulted in an increase in global temperature. The consequences of such an increase in temperature may well be dangerous. Sea levels will rise, completely inundating a number of low-lying island nations and flooding many coastal cities. Many plant and animal species may probably be forced to go into extinction, agricultural regions will be disrupted, and the frequency of droughts is likely to increase.

1.2.2 Forest Wood

Forests are very important for maintaining ecological balance and provide many environmental benefits. In addition to timber and paper products, forests provide wildlife habitat, prevent flooding and soil erosion, help provide clean air and water, and contain tremendous biodiversity. Forests are also an important defense against global climate change. Forests produce life-giving oxygen and consume carbon dioxide, the compound most responsible for global warming through photosynthesis, thereby reducing the effects of global warming.
Fig. 1.2. Deforestation causes desertification (A) A conserved forest (B).

Forests provide habitat for a wide variety of plants and animals and perform many other important functions that affect humans. The forest canopy (the treetops) and root systems provide natural filters for the water we use from lakes and rivers. When it rains the forest canopy intercepts and re-distributes precipitation that can cause flooding and erosion, the wearing away of topsoil. Some of the precipitation flows down the trunks as stemflow, the rest percolates through the branches and foliage as throughfall. The canopy is also able to capture fog, which it distributes into the vegetation and soil. Forests also increase the ability of the land to store water.

1.2.3 Soil

Soil, a mixture of mineral, plant, and animal materials, is essential for most plant growth and is the basic resource for agricultural production. In the process of developing the land and clearing away the vegetation that holds water and soil in place, erosion has devastated soils worldwide. The rapid deforestation taking place in the tropics is especially damaging because the thin layer of soil that remains is fragile and quickly washes away when exposed to the heavy tropical rains. Globally, agriculture accounts for 28 percent of the nearly 2 billion hectares of soil that have been degraded by human activities; overgrazing is responsible for 34 percent; and deforestation is responsible for 29 percent.

1.2.4 Water

Clean freshwater resources are essential for drinking, bathing, cooking, irrigation, industry, and for plant and animal survival. Due to overuse, pollution, and ecosystem degradation the sources of most freshwater supplies—groundwater (water located below the soil surface), reservoirs, and rivers—are under severe and increasing environmental stress. Over 95 percent of urban sewage in developing countries is discharged untreated into surface waters such as rivers and harbors.

About 65 percent of the global freshwater supply is used in agriculture and 25 percent is used in industry. Freshwater conservation therefore requires a reduction in wasteful practices like inefficient irrigation, reforms in agriculture and industry, and strict pollution controls worldwide.

Fig. 1.3. A polluted river
1.2.5 Energy

Human beings have been using energy throughout history. People use energy for industrial production, transportation, heating, cooling, cooking, and lighting. The world's energy supply depends on different resources. Traditional fuels such as firewood and animal waste, for example, are significant energy sources in many developing countries. Fossil fuels account for more than 90 percent of global energy production but their use causes air pollution and are considered to be problematic resources.

One of the most significant factors that have contributed to environmental degradation is population growth. The demand for additional food and shelter that accompanies population growth will enhance deforestation, cultivation of more land, the use of fertilizers, damming of rivers, and urbanization. These activities will subsequently contribute to global ecological imbalance and environmental pollution. In the following subunit, we shall briefly discuss the impacts of population growth on the environment.

1.3 Population Increase and the Environment

The world population is increasing at an alarming rate. From 1930 to present, it has risen from 2 billion to 5.3 billion. And it is expected to rise again to over 8 billion by 2050. The demands of increasing population coupled with the desire of most people for a higher material standard of living are resulting in worldwide pollution on a massive scale.

Environmental problems have led to shortages of food, clean water, materials for shelter, and other essential resources. As forests, land, air, and water are degraded, people who live directly off these natural resources suffer most from the effects.

Global environmental degradation may result from a variety of factors, including overpopulation and overuse of land and other resources. Intensive farming, for instance, depletes soil fertility, thus decreasing crop yields. Environmental degradation also results from pollution. Polluting industries include mining, power generation, and chemical production. Other major sources of pollution include automobiles and agricultural fertilizers.

In developing countries, deforestation has had particularly devastating environmental effects. Many rural people, particularly in tropical regions, depend on forests as a source of food and other resources, and deforestation damages or eliminates these supplies. Forests also absorb many pollutants and water from extended rains; without forests, pollution increases and massive flooding further decreases the usability of the deforested areas.

Poor land management and increasing population are factors that promote increased irrigation, improper cultivation or overcultivation, and increased numbers of livestock. These events alter the land and the soil, diminish the resources, and increase the chances of desertification.
Over the last few years urbanization of rural areas has increased. As agriculture, more traditional local services, and small-scale industry give way to modern industry the urban and related commerce with the city drawing on the resources of an ever-widening area for its own sustenance and goods to be traded or processed into manufactures. Urbanization is among the most significant factors that aggravated environmental degradation. In the following subunit we shall briefly discuss on the impacts of urbanization on the environment.

### 1.4 Urbanization and the Environment

Demographically, the term urbanization denotes redistribution of populations from rural to urban settlements. The 20th century has witnessed a rapid urbanization of the world’s population. The global proportion of urban population rose dramatically from 13% (220 million) in 1900, to 49% (3.2 billion) in 2005. It is also projected that the figure is likely to rise to 60% (4.9 billion) by 2030.

Urbanization occurs naturally from an effort to improve opportunities for jobs, education, housing, and transportation and reduce expenses in commuting and transportation. Living in cities permits individuals and families to take advantage of the opportunities of proximity, diversity, and marketplace competition. With proper planning and long-term vision, dense settlement patterns offer economies of scale that can actually reduce pressures on natural resources from population growth and increase energy efficiency. Since people live close together and need less space in cities, each person requires less critical infrastructure like sewers, electricity, and roads than in decentralized human settlements. However, along with the above social and economic benefits of urbanization comes a number of environmental ills.

In recent decades, valuable farmlands have faced a new threat posed by the urbanization of rural areas. Prime agricultural land has been turned into subdivisions and paved over to create parking lots and streets. Increasing urban sprawl has led to the need for more highways. In a vicious continuing circle, the availability of new highway systems has enabled even more development. The final result of this pattern of development has been the removal of once productive farmland from agricultural use.

The world’s cities account for 75 percent of global energy consumption, 80 percent of greenhouse gas emissions, and a disproportionate share of resource use, such as food, timber, and steel. Due to this most cities in the world experience the worst urban air pollution as a result of rapid industrialization and increased motorized transport. Worldwide, urban air pollution is estimated to cause one million premature deaths each year.
1.5 Industrialization and the Environment

The world population is increasing at an alarming rate. From 1930 to present it rose from 2 billion to 5.3 billion. And it is expected to rise again to over 8 billion in 2050. The demands of the increasing population coupled with the desire of most people for a higher material standard of living has intensified industrialization. These industrial activities, aided by modern technologies, provide the food, shelter, and goods that humans need for their well-being and survival.

Industrial manufacturing processes may consist of the synthesis of a chemical from raw materials, casting of metal or plastic parts, or any of the other things that is needed to produce a certain product. Each of these processes carries with it the potential to cause significant air and water pollution and production of hazardous wastes. The earlier in the design and development process that environmental considerations are taken into account, the more “environmentally friendly” a manufacturing process will be.

Over the past 30 years, industrial production has been a major source of pollution in urban areas and a significant driver of intensified resource use.

1.5.1 Environmental Pollutions Resulting from Industrialization

Try to answer the following stimulating questions before you start reading the notes given in this sub-unit and then go to the readings to find the answers.

Have you ever seen the air over a big city turned cloudy? What do you think are the components of such a cloudy air? How is it formed?

1.5.1.1 Smog and Acid Precipitation

Most air pollution comes from one human activity: burning fossil fuels—natural gas, coal, and oil—to power industrial processes and motor vehicles. This results in the emission of harmful chemical compounds such as carbon dioxide, carbon monoxide, nitrogen oxides, sulfur dioxide, and tiny solid particles—including lead from gasoline additives—called particulates. Various volatile organic chemicals (VOCs), generated from incompletely burned fuels, also enter the air.

Carbon dioxide is one of the green house gases which contribute significantly to global warming. Sulfur dioxide and nitrogen oxide emissions are the principal causes of acid rain in many parts of the world. Sulfur dioxide and nitrogen oxides emitted into the atmosphere, are absorbed by rain to form sulphuric acid and nitric acid. These acids are bad for the lungs and attack anything made of limestone, marble, or metal.

Smog is a type of air pollution produced when sunlight acts upon motor vehicle exhaust gases to form harmful substances such as ozone (O₃), aldehydes and peroxyacetyl nitrate (PAN). Before the automobile age, most smog came from burning coal. Burning gasoline in motor vehicles is the main source of smog in most regions today.
Powered by sunlight, oxides of nitrogen and volatile organic compounds react in the atmosphere to produce photochemical smog. Ozone in the lower atmosphere is a poison—it damages vegetation, kills trees, irritates lung tissues, and attacks rubber. Smog spoils views and makes outdoor activity unpleasant. The effects of smog are even worse for the very young and the very old people who suffer from asthma or heart disease. Smog can cause breathing difficulties, headaches and dizziness. In extreme cases, smog can lead to mass illness and death, mainly from carbon monoxide poisoning.

1.5.1.2 Soil and water pollution

The agriculture and mining industries have profoundly contributed to soil and water pollution. Agriculture has rapidly changed vast forest and grassland areas into cropland.

Mining disturbs groundwater aquifers. Water seeping through mines and mine tailings may become polluted. Pyrite, FeS$_2$, is a mineral that is commonly associated with coal. In coal mining, one of the more common and damaging effects on water occurs when this mineral is exposed to air and becomes oxidized to sulphuric acid by bacterial action to produce acid mine water.

While processing mined materials various beneficiation processes are employed to separate the useful fraction of the ore, leaving a residue of tailings which are laden with various chemicals which pollute the soil and water bodies in the surrounding. For example, residues left from the beneficiation of coal are often enriched in pyrite, FeS$_2$, which is oxidized microbiologically and chemically to produce damaging acidic drainage (acid mine water) which can pollute the soil, surface water and underground water.

1.5.1.3 Modifications of the Climate

Human activities are reaching a point at which they may be adversely affecting the climate. Global warming, due to the emission of large quantities of carbon dioxide and other greenhouse gases into the atmosphere has resulted in substantial climatic change. Another way is through the release of gases, particularly chlorofluorocarbons (Freons) that may cause destruction of vital stratospheric ozone.
Formative Assessment

1. Part of the geosphere which is in direct contact with the atmosphere is the
   a) outer core, b) lower mantle, c) upper mantle, d) none

2. Layer of the geosphere which is most affected by human activity is the,
   a) lithosphere b) upper mantle c) lower mantle d) outer core

3. The relatively thin zone of the atmosphere, geosphere and hydrosphere that is capable of supporting life is known as,
   a) anthroposphere b) biosphere c) environment d) lithosphere

4. Which of the following does not contribute to global warming?
   a) Deforestation c) the use of fossil fuels as energy source
   b) Afforestation d) a & b

5. Global environmental degradation may result from
   a) underpopulation
   b) existence of large areas covered by natural forest
   c) Intensive farming
   d) protecting wild life

6. Compared to decentralized human settlements, which of the following is an advantage of urbanization with regard to the environment?
   a) Reducing the pressures on natural resources and increase energy efficiency.
   b) Greater critical infrastructure requirement by each person
   c) Conversion of prime agricultural lands into parking lots and streets
   d) Rapid industrialization and increased motorized transport
7. The principal emissions which are the causes of acid rain in many parts of the world are
   a) Oxygen and carbondioxide                c) methane and carbondioxide
   b) Sulfur dioxide and nitrogen oxide       d) carbonmonoxide and carbondioxide

8. Today the main source of smog in most regions is
   a) Fertilizers and pesticides used in modern agricultural practices
   b) Pollutant gases evaporating from large water bodies
   c) Unsafe disposal of volatile organic pollutants
   d) Burning gasoline in motor vehicles

9. Which of the following is not an effect of smog?
   a) It makes breathing difficult       c) It may cause death
   b) It causes headaches                   d) None

10. Pyrite exposure to air leads to the formation of
   a) sulfur                    c) nitric acid
    b) sulfuric acid          d) Hydrochloric acid

**Answers**

1. d) none
2. a) lithosphere
3. b) biosphere
4. b) Afforestation
5. c) Intensive farming
6. a) Reducing the pressures on natural resources and increase energy efficiency.
7. b) Sulfur dioxide and nitrogen oxide
8. d) Burning gasoline in motor vehicles
9. d) None
10. b) sulfuric acid
Learning Activity 2

Atmospheric chemistry and Air pollution

Summary of the Learning Activity

The atmosphere provides a direct link between industrial activity, the biosphere, the lithosphere and ocean, and human beings. As students of environmental chemistry, you should be able to address current issues such as: climate change, air pollution, the fate of industrial emissions, ozone depletion; in atmospheric science at a high level.

Therefore, after completing this section, you should be able to

• Explain the scope of atmospheric chemistry and describe the composition of the earth’s atmosphere.
• Explain the regions of the atmosphere defined on the basis of temperature
• Discuss the characteristics of the major regions of the atmosphere
• Describe the chemical reactions taking place in the atmosphere
• Define air pollution and describe its natural and anthropogenic sources
• Explain the various ways of classifying air pollutants
• Explain the relationship between air-pollution and acid-rain
• Describe the influence of air-pollution on ozone layer depletion and global warming

List of Relevant Readings


List of Relevant resources

• Computer with internet facility to access links and relevant copy write free resources.
• CD-Rom accompanying this module for supplemental readings and to check the answers for the exercises given in the learning activity.

List of Relevant Useful Links

Global Warming, Acid Rain, Ozone Depletion, in VIRTUAL CHEMBOOK, at http://www.elmhurst.edu/~chm/vchembook/index.html

Global Warming and Climate Change, at http://www.gcrio.org/gwcc/index.htm
Provides relevant discussions in part one and part two. Part one discusses the mechanism on how burning coal, oil and natural gas releases CO$_2$ into the atmosphere and results in global warming. In addition to this, other human activities that contribute to global warming are also emphasized.

The second part discusses the impacts of global warming. How heating, cooling, water use, and sea level will be affected due to global warming, and the effect of a large or fast change in climate on plants and animals in the natural environment are described in depth.

Reading Assignment

a) Review the chapter on gas laws in your general chemistry module.
b) Read chapter 9 in Manahan.
c) Read the word file ‘Comp-R-airpollutants’ in the compulsory readings to learn more on the formation of oxides in the atmosphere.
Unit II: Atmospheric chemistry and Air pollution (35 hrs)

Atmospheric Chemistry
- Introduction
- Earth’s Atmosphere
- Temperature and the Atmospheric layers
- Characteristics of the Major Regions of the Atmosphere
- Atmospheric Chemical Reactions

Air Pollution,
- Classification of Air Pollutants,
- Major Sources of Air Pollutants,
- Air Pollution and Acid-Rain,
- Air Pollution and Ozone Depletion,
- Global Warming,
- Solving the Problem
2.1 Atmospheric Chemistry

Pollution is changing Earth’s atmosphere so that it lets in more harmful radiation from the Sun. The temperature increase, known as global warming, is predicted to affect world food supply, alter sea level, make weather more extreme, and increase the spread of tropical disease.

As a chemistry teacher, you are expected to contribute your part to the solution of the current globally burning issue of atmospheric pollution. You should be able to describe the composition of the atmosphere, the major contributors to atmospheric pollution and the way these pollutants are accumulated in the atmosphere. In this unit, we shall discuss the chemistry of the atmosphere and the major pollutants of the atmosphere, describe the way these pollutants are formed and accumulated in the atmosphere and the threat posed by the pollutants.

2.1.1 Introduction

Atmospheric chemistry: is a branch of atmospheric science in which the chemistry of the Earth’s atmosphere and that of other planets is studied.

The composition and chemistry of the atmosphere is of importance for several reasons, but primarily because of the interactions between the atmosphere and living organisms. The composition of the Earth’s atmosphere has been changed by human activity and some of these changes are harmful to human health, crops and ecosystems. Examples of problems which have been addressed by atmospheric chemistry include acid rain, photochemical smog and global warming. Atmospheric chemistry seeks to understand the causes of these problems, and by obtaining a theoretical understanding of them, allow possible solutions to be tested and the effects of changes in government policy evaluated.
2.1.2 Earth’s Atmosphere

Earth’s atmosphere is a layer of gases surrounding the planet Earth and retained by the Earth’s gravity. It contains roughly 78% nitrogen, 21% oxygen, 0.93% argon, 0.04% carbon dioxide, and trace amounts of other gases, in addition to water vapor. This mixture of gases is commonly known as air. The atmosphere protects life on earth by absorbing solar UV radiation and reducing temperature extremes between day and night.

The gases ozone, water vapor, and carbon dioxide are only minor components of the atmosphere, but they exert a huge effect on the Earth by absorbing radiation. Ozone in the upper atmosphere filters out the ultraviolet light below about 360 nm that is dangerous for living things. In the troposphere ozone is an undesirable pollutant. It is toxic to animals and plants, and it also damages materials.

The atmosphere slowly becomes thinner and fades away into space. Therefore, there is no definite boundary between the atmosphere and outer space. Seventy five percent of the atmosphere’s mass is within 11 km of the planetary surface.

2.1.3 Temperature and the Atmospheric layers

Although atmospheric pressure decreases in a regular way at higher altitudes the profile of temperature versus altitude is much more complex. The temperature of the Earth’s atmosphere varies with altitude and the mathematical relationship between temperature and altitude varies between the various atmospheric layers:

![Variation of average temperature with altitude.](image)
Four regions of the atmosphere: the troposphere, stratosphere, mesosphere and thermosphere, have been defined based on the temperature curve shown in Fig. 2.1.

The **Troposphere** is the region nearest the earth’s surface. This is the region between the surface of the earth and 7 km altitude at the poles and 17 km at the equator with some variation due to weather factors. Air temperature drops uniformly with altitude at a rate of approximately 6.5° Celsius per 1000 meters. Top is reached at an average temperature of -56.5°C.

In the **stratosphere**, temperature remains constant with height in the first 9 kilometers (called an isothermal layer) and then goes on increasing.

Above the stratosphere in the region from 50 to about 80 km, the temperature again decreases in the **mesosphere**. The atmosphere reaches its coldest temperatures (about -90°C) at the top layer of the mesosphere (a height of about 80km).

The upper atmosphere is characterized by the presence of significant levels of electrons and positive ions. Because of the rarefied conditions, these ions may exist in the upper atmosphere for long periods before recombining to form neutral species. At altitudes of approximately 50 km and up, ions are so prevalent that the region is called the **ionosphere**. Ultraviolet light is the primary producer of ions in the ionosphere. In darkness, the positive ions slowly recombine with free electrons. The process is more rapid in the lower regions of the ionosphere where the concentration of species is relatively high.

Atmospheric temperature again increases at the thermosphere. Temperature in this layer can be as high as 1200°C.

The boundaries between these regions are named the **tropopause**, **stratopause**, **mesopause**, and **thermopause**. The average temperature of the atmosphere at the surface of Earth is 14 °C. Passenger jets normally fly near the top of the troposphere at altitudes of 10 to 12 km, and the world altitude record for aircraft is 37.65 km—roughly in the middle of the stratosphere.

### 2.1.4 Characteristics of the Major Regions of the atmosphere

#### 2.1.4.1 The Troposphere

This is the region close to the surface of the Earth. Excluding water vapor, the major gaseous components of the atmosphere in this region are N\textsubscript{2} (78.1%), O\textsubscript{2} (21%), Ar (0.9%), CO\textsubscript{2} (0.03%) and variable amounts of CH\textsubscript{4}, NO\textsubscript{2}, CO, N\textsubscript{2}O, H\textsubscript{2}, SO\textsubscript{2}, Kr, Ne and O\textsubscript{3}. About 80% of the total mass of the atmosphere is contained in this layer of the atmosphere.

In the troposphere, air temperature drops uniformly with altitude at a rate of approximately 6.5° Celsius per 1000 meters. Top is reached at an average temperature of -56.5°C.
2.1.4.2 The Stratosphere

The stratosphere contains about 19.9 % of the total mass found in the atmosphere. A thin layer in the upper stratosphere (known as the ozone layer) has a high concentration of ozone.

Ozone absorbs ultraviolet light very strongly in the region 220-330 nm. By doing so, ozone converts the radiation’s energy to heat and is responsible for the temperature maximum encountered at the boundary between the stratosphere and the mesosphere at an altitude of approximately 50 km.

The region of maximum ozone concentration is found within the range of 25-30 km high in the stratosphere where it may reach 10 ppm. However, the temperature maximum occurs at a higher altitude. This is due to the fact that ozone is such an effective absorber of UV radiation and most of this radiation is absorbed in the upper stratosphere where it generates heat. Only a small fraction reaches the lower altitudes, where ozone is more concentrated, which remain relatively cool.

This layer is primarily responsible for absorbing the ultraviolet radiation from the sun. The higher temperatures found in the upper region of the stratosphere occurs because of this localized concentration of ozone gas molecules. Ozone molecules absorb UV light creating heat energy that warms the stratosphere.

2.1.4.3 The Mesosphere

**Mesosphere:** The layer above the stratosphere is known as the Mesosphere and this layer extends from about 50 to 80 km. It is separated from the thermosphere by a thin layer known as the mesopause.

Temperature goes on decreasing in the mesosphere and the atmosphere reaches its coldest temperatures (about -90°C) at the end of the mesosphere (at a height of about 80km).

2.1.4.4 The Thermosphere

This is part of the atmosphere which is above 80 km altitude. In the outer space of the thermosphere, most particles consist of single atoms, H, He, and O etc. At lower altitude (200 - 100 km), diatomic molecules N₂, O₂, NO etc are present. The high temperature in this layer is generated from the absorption of intense solar radiation by oxygen molecules (O₂).

In this region of the atmosphere, while temperature seems extreme, the amount of heat energy involved is very small. Since molecules which can store heat are small in quantity. (Note: that heat stored is directly proportional to quantity of substance).

The air in the thermosphere is extremely thin with large distance between gas molecules. This makes the process of measuring the temperature of the thermosphere with a thermometer very difficult.
2.1.5 Atmospheric Chemical Reactions

Two constituents of utmost importance in atmospheric chemistry are radiant energy from the sun, predominantly in the ultraviolet region of the spectrum, and the hydroxyl radical, HO•. The former provides a way to pump a high level of energy into a single gas molecule to start a series of atmospheric chemical reactions, and the latter is the most important reactive intermediate of daytime atmospheric chemical phenomena.

Nitrogen dioxide, NO₂, is one of the most photochemically active species found in a polluted atmosphere. A species such as NO₂ may absorb light to produce an electronically excited molecule,

\[ \text{NO}_2 + \text{hv} \rightarrow \text{NO}_2^* \]

An electronically excited molecule is a molecule which has absorbed energetic electromagnetic radiation in the UV or visible regions of the spectrum.

**Electronically excited molecules, free radicals, and ions consisting of electrically-charged atoms or molecular fragments** are the three relatively reactive and unstable species that are encountered in the atmosphere. They are strongly involved in atmospheric chemical processes.

A) Formation of Free Radicals

Free radicals are atoms or groups of atoms with unpaired electrons. Such species may be produced by the action of energetic electromagnetic radiation on neutral atoms or molecules. The strong pairing tendencies of the unpaired electrons make free radicals highly reactive and are involved with most significant atmospheric chemical phenomena.

The hydroxyl radical, HO•, is the single most important reactive intermediate species in atmospheric chemical processes. It is formed by several mechanisms. At higher altitudes it is produced by photolysis of water:

\[ \text{H}_2\text{O} + \text{hv} \rightarrow \text{HO}^* + \text{H} \]

In the relatively unpolluted troposphere, hydroxyl radical is produced as the result of the photolysis of ozone,

\[ \text{O}_3 + \text{hv}(\lambda < 315 \text{ nm}) \rightarrow \text{O}^* + \text{O}_2 \]

\[ \text{O}^* + \text{H}_2\text{O} \rightarrow 2\text{HO}^* \]

Hydroxyl radical is removed from the troposphere by reaction with methane or carbon monoxide:
CH₄ + HO• → H₃C• + H₂O
CO + HO• → CO₂ + H

The hydrogen atom produced in the second reaction reacts with O₂ to produce hydroperoxyl radical which in turn may react with another hydroperoxyl or hydroxyl radical

H + O₂ → HOO•
HOO• + HO• → H₂O + O₂
HOO• + HOO• → H₂O₂ + O₂

or reactions that regenerate hydroxyl radical:

HOO• + NO → NO₂ + HO•
HOO• + O₃ → 2O₂ + HO•

B) Acid – Base Reactions in the Atmosphere

The atmosphere is slightly acidic because of the presence of a low level of carbon dioxide, which dissolves in atmospheric water droplets and dissociates slightly:

\[
\text{CO}_2(g) \rightleftharpoons \text{CO}_2(aq)
\]

\[
\text{CO}_2(aq) + \text{H}_2\text{O} \rightarrow \text{H}^+ + \text{HCO}_3^-
\]

In terms of pollution, however, strongly acidic HNO₃ and H₂SO₄ formed by the atmospheric oxidation of N oxides, SO₂, and H₂S are much more important because they lead to the formation of damaging acid rain.

Basic species are relatively less common in the atmosphere. Particulate calcium oxide, hydroxide, and carbonate can get into the atmosphere from ash and ground rock, and can react with acids such as in the following reaction:

\[
\text{Ca(OH)}_2(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{CaSO}_4(s) + 2\text{H}_2\text{O}
\]
The most important basic species in the atmosphere is gas-phase ammonia, \( \text{NH}_3 \). The major source of atmospheric ammonia is the biodegradation of nitrogen containing biological matter and bacterial reduction of nitrate:

\[
\text{NO}_3^- (aq) + 2\{\text{CH}_2\text{O}\} (\text{biomass}) + \text{H}^+ \rightarrow \text{NH}_3 (g) + 2\text{CO}_2 + \text{H}_2\text{O}
\]

Ammonia is the only water soluble base present at significant levels in the atmosphere. This makes it particularly important as a base in the air. Dissolved in atmospheric water droplets, it plays a strong role in neutralizing atmospheric acids:

\[
\text{NH}_3 (aq) + \text{HNO}_3 (aq) \rightarrow \text{NH}_4\text{NO}_3 (aq)
\]
\[
\text{NH}_3 (aq) + \text{H}_2\text{SO}_4 (aq) \rightarrow \text{NH}_4\text{HSO}_4 (aq)
\]

C) Reactions of Atmospheric Oxygen

In addition to \( \text{O}_2 \), the upper atmosphere contains oxygen atoms, \( \text{O} \); excited oxygen molecules, \( \text{O}_2^* \); and ozone, \( \text{O}_3 \). Atomic oxygen, \( \text{O} \), is stable primarily in the thermosphere, where the atmosphere is so rarefied that the three-body collisions necessary for the chemical reaction of atomic oxygen seldom occur. Atomic oxygen is produced by a photochemical reaction:

\[
\text{O}_2 + \text{hv} \rightarrow \text{O} + \text{O}
\]

At altitudes exceeding about 80 km, the average molecular weight of air is lower than the 28.97 g/mole observed at sea level because of the high concentration of atomic oxygen. This condition has divided the atmosphere into a lower section with a uniform molecular weight (homosphere) and a higher region with a nonuniform molecular weight (heterosphere).

Molecular oxygen and excited oxygen atoms (\( \text{O}^* \)) are produced due to the photolysis of atmospheric ozone

\[
\text{O}_3 + \text{hv}(\lambda < 308 \text{ nm}) \rightarrow \text{O}^* + \text{O}_2
\]

or by highly energetic chemical reactions such as

\[
\text{O} + \text{O} + \text{O} \rightarrow \text{O}_2 + \text{O}^*
\]
Oxygen ion, O⁺, which may be produced by ultraviolet radiation acting upon oxygen atoms,

\[ \text{O} + \text{hv} \rightarrow \text{O}^+ + \text{e}^- \]

is the predominant positive ion in some regions of the ionosphere. It may react with molecular oxygen or nitrogen to form other positive ions:

\[ \text{O}^+ + \text{O}_2 \rightarrow \text{O}_2^+ + \text{O} \]
\[ \text{O}^+ + \text{N}_2 \rightarrow \text{NO}^+ + \text{N} \]

In intermediate regions of the ionosphere, O₂⁺ is produced by absorption of ultraviolet radiation at wavelengths of 17-103 nm.

\[ \text{O}_2 + \text{hv} \rightarrow \text{O}_2^+ + \text{e}^- \]

and by the reaction between N₂⁺ and O₂:

\[ \text{N}_2^+ + \text{O}_2 \rightarrow \text{N}_2 + \text{O}_2^+ \]

Atmospheric ozone is produced by photochemical dissociation of molecular oxygen followed by a three body reaction

\[ \text{O}_2 + \text{hv} \rightarrow \text{O} + \text{O} \]
\[ \text{O} + \text{O}_2 + \text{M} \rightarrow \text{O}_3 + \text{M(increased energy)} \]

in which M is another species, such as a molecule of N₂ or O₂, which absorbs the excess energy given off by the reaction and enables the ozone molecule to stay together.

In addition to undergoing decomposition by the action of ultraviolet radiation, stratospheric ozone reacts with atomic oxygen, hydroxyl radical, and NO:

\[ \text{O}_3 + \text{hv} \rightarrow \text{O}_2 + \text{O} \]
\[ \text{O}_3 + \text{O} \rightarrow \text{O}_2 + \text{O}_2 \]
\[ \text{O}_3 + \text{HO}^* \rightarrow \text{O}_2 + \text{HOO}^* \]

The HO• radical is regenerated from HOO• by the reaction,

\[ \text{HOO}^* + \text{O} \rightarrow \text{HO}^* + \text{O}_2 \]
D) Reactions of Atmospheric Nitrogen

Unlike oxygen, molecular nitrogen is not readily dissociated by ultraviolet radiation. However, at altitudes exceeding approximately 100 km, atomic nitrogen is produced by photochemical reactions:

\[ \text{N}_2 + h\nu \rightarrow \text{N} + \text{N} \]

Other reactions which may produce monatomic nitrogen are:

\[ \text{N}_2^+ + \text{O} \rightarrow \text{NO}^+ + \text{N} \]
\[ \text{NO}^+ + e^- \rightarrow \text{N} + \text{O} \]
\[ \text{O}^+ + \text{N}_2 \rightarrow \text{NO}^+ + \text{N} \]

In the region above 105 km of the ionosphere a plausible sequence of reactions by which \( \text{NO}^- \) is formed is the following:

\[ \text{N}_2 + h\nu \rightarrow \text{N}_2^+ + e^- \]
\[ \text{N}_2^+ + \text{O} \rightarrow \text{NO}^+ + \text{N} \]

In the lowest region of the ionosphere, which extends from approximately 50 km in altitude to approximately 85 km, \( \text{NO}^- \) is produced directly by ionizing radiation:

\[ \text{NO} + h\nu \rightarrow \text{NO}^+ + e^- \]

Note: Try to solve the following exercise and check the answer in file ‘Comp-R-Ans-to-exer’ in the accompanying CD.
Exercise 1

1. Exhaust gases such as oxides of nitrogen are known to contribute for the formation of atmospheric ozone.

Show the mechanism for the formation of ozone from these gases. Point out the ratio of the oxides of nitrogen favorable for the formation and destruction of atmospheric ozone.

E) Atmospheric Carbon dioxide

Although only about 0.035% (350 ppm) of air consists of carbon dioxide, it is the atmospheric “nonpollutant” species of most concern. Chemically and photochemically, however, it is a comparatively insignificant species because of its relatively low concentrations and low photochemical reactivity. The one significant photochemical reaction that it undergoes, and a major source of CO at higher altitudes, is the photodissociation of CO$_2$ by energetic solar UV radiation in the stratosphere:

\[
\text{CO}_2 + h\nu \rightarrow \text{CO} + \text{O}
\]

F) Atmospheric Water

The water vapor content of the troposphere is normally within a range of 1–3% by volume with a global average of about 1%. However, air can contain as little as 0.1% or as much as 5% water. The percentage of water in the atmosphere decreases rapidly with increasing altitude.

The cold tropopause serves as a barrier to the movement of water into the stratosphere. Thus, little water is transferred from the troposphere to the stratosphere, and the main source of water in the stratosphere is the photochemical oxidation of methane:

\[
\text{CH}_4 + 2\text{O}_2 + h\nu \xrightarrow{\text{(several steps)}} \text{CO}_2 + 2\text{H}_2\text{O}
\]

The water thus produced serves as a source of stratospheric hydroxyl radical as shown by the following reaction:

\[
\text{H}_2\text{O} + h\nu \rightarrow \text{HO}^\cdot + \text{H}
\]
2.2 Air Pollution

Air Pollution can be defined as the addition of harmful substances to the atmosphere resulting in damage to the environment, human health, and quality of life.

Air pollution causes breathing problems and promotes cancer. It harms plants, animals, and the ecosystems in which they live. Some air pollutants return to Earth in the form of acid rain and snow, which corrode statues and buildings, damage crops and forests, and make lakes and streams unsuitable for fish and other plant and animal life.

Especially the pollutants that result from the use of combustion as a source of energy: oxides of sulfur, oxides of nitrogen, and carbon monoxide.

2.2.1 Classification of Air Pollutants

There are a number of ways of classifying air pollutants. Most commonly they are classified on the basis of 1) differences in their physical or chemical characteristics, 2) by their origin, 3) by the nature of the response they elicit, 4) by their legal status.

1) Based on differences in their physical or chemical characteristics

Aerosols:- are tiny particles dispersed in gases and include both liquid and solid particles. Air pollution terminology relating to atmospheric aerosols includes dusts, fog, fumes, hazes, mists, particulate matter, smog, smoke, and soot.

Gases and vapors:- are composed of widely separated freely moving molecules which will expand to fill a larger container and exert a pressure in all directions. A substance is a true gas if it is far removed from the liquid state (i.e. the temperature of the substance is above its critical point). A vapor is a substance in the gaseous state which is not far from being a liquid (i.e. it can be condensed to a liquid relatively easily).
2) Based on their origin

Air pollutants are classified in different ways based on their origin. These are:

A) Mobile and Stationary sources

Mobile sources of emissions include automobiles, trains, and airplanes while stationary sources include all other sources. Electric power plants, chemical manufacturing industries, air strippers, and soil vapor extraction operations are examples of stationary sources.

B) Direct and Indirect

A direct source emits pollutants directly while indirect sources do not themselves emit pollutants but attract mobile sources (e.g. a shopping mall, athletic stadium).

C) Point source and Area sources

A point source is defined as a stationary source whose emissions significantly impact air quality. Area sources are those that, individually do not have significant impact on air quality but, are significant when viewed together (e.g. dry cleaners, open burning).

3) Based on the way pollutants reach the atmosphere

Air pollutants are classified as primary and secondary pollutants based on the way they reach the atmosphere

Primary pollutants are those that are emitted directly into the atmosphere from an identifiable source. Examples include carbon monoxide and sulfur dioxide. Secondary pollutants, on the other hand, are those that are produced as a result of chemical reactions in the atmosphere. For example, ozone, which is a major component of urban smog, formed as a result photochemical reactions between oxides of nitrogen, VOCs, and other atmospheric constituents, is a secondary pollutant. In the case of secondary pollutants, the precursors to the pollutant are generally regulated.

4) Based on their legal status

Based on the way in which they are regulated, or their legal status, six pollutants have been identified by the EPA as criteria pollutants because they are both common and detrimental to human health. These are: particulate matter having diameters of 10 μm or less (PM10), sulfur dioxide, carbon monoxide, nitrogen dioxide, ozone, and lead. For each criteria pollutant, EPA has established a primary and secondary ambient air quality standard. The purpose of the primary standard is to protect public health while the secondary standard is set at a level to protect public welfare from adverse effects. Collectively, these standards are known as the National Ambient Air Quality Standards (or NAAQS).
2.2.2 Major Sources of Air Pollution

Human activities such as: burning coal and petroleum products (gasoline, kerosene, fuel oil etc; driving a car, and industrial activities, such as manufacturing products or generating electricity are among the major sources of air pollutants.

The generation of energy through the combustion of fossil fuels produces plenty of water and carbon dioxide, which contributes to global warming.

When coal, gasoline, and similar fuels are burned, the hydrocarbons and other impurities in them are oxidized. The sulfur of the pyrite that remains in coal, for example, oxidizes to sulfur dioxide, an irritating gas with a harsh, acrid odor. The reaction for the oxidation is

$$4\text{FeS}_2 + 11\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3 + 8\text{SO}_2$$

pyrite     oxygen     iron oxide     sulfur dioxide

The oxides formed under this condition combine with water vapor in the air to form acids, which return to the ground as acid rain.

Powered by sunlight, oxides of nitrogen and volatile organic compounds react in the atmosphere to produce photochemical smog. Smog contains ozone, a form of oxygen gas made up of molecules with three oxygen atoms rather than the normal two. In the lower atmosphere Ozone is a poison—it damages vegetation, kills trees, irritates lung tissues, and attacks rubber. The severity of smog is determined by measuring the ozone level in the smog. When the ozone level is high, other pollutants, including carbon monoxide, are usually present at high levels as well.

The very young, the very old, and people who suffer from asthma or heart disease, are more seriously affected by smog. Smog may cause headaches or dizziness and can cause breathing difficulties. In extreme cases, it can lead to mass illness and death, mainly from carbon monoxide poisoning.

Still another pollutant, a product of the incomplete combustion of carbon or organic compounds, such as the hydrocarbons of gasoline, one that we can’t see and that produces no sense of irritation, is carbon monoxide, CO. This gas is known as the silent killer because it is odorless, tasteless, and invisible. Its major symptom is a drowsiness sometimes accompanied by headache, dizziness, and nausea. CO is primarily a pollutant of cities and usually fluctuates with flow of traffic.
B) Natural Sources

Some of the pollutants resulting from human activities also come from natural sources. For example, Volatile Organic Compounds (VOCs) are emitted into the atmosphere from forest fires or simply by evaporating. The common air pollutant VOCs include

- volatile hydrocarbon components of consumer products such as paint thinners, roof tar, and glazing compounds, which are often listed on ingredients labels as “petroleum distillates,”
- evaporating solvents and propellants of personal care and household products such as nail polish, deodorants, after-shave lotions, hair sprays, and insecticides,
- ethyl acetate and more exotic additives that we exhale when we chew gum and breath fresheners for what advertisers call a “fresh, clean breath.”

Volcanoes spew out sulfur dioxide and large amounts of volcanic ash. Unlike pollutants from human activity, however, naturally occurring pollutants tend to remain in the atmosphere for a short time and do not lead to permanent atmospheric change.

2.2.3 Air Pollution and Acid-Rain

Reading Assignment

1. Read the file ‘Comp-R-airpollutants’ in the compulsory readings. The reading gives you a brief explanation on how natural presence of carbon dioxide in the earth’s atmosphere makes rain acidic with or without air pollution.

Rainwater which was considered to be the purest form of water available in the past, is now known to be often contaminated by pollutants in the air. In the presence of atmospheric moisture, gases such as sulfur dioxide and oxides of nitrogen, resulting from industrial emissions, turn into droplets of pure acid floating in smog, known as acid rain.

![Fig. 2.4 Acid-Rain formation](image-url)
These airborne acids are bad for the lungs and attack anything made of limestone, marble, or metal. Forests and lakes that are far away from industrial activities may be damaged by acid rain resulting from pollutants that may be carried by winds in the troposphere and descend in acid form, usually as rain or snow. Leaves of plants are burned and lakes will be too acidic to support fish and other living things due to acid precipitation.

Note: Try to solve the following exercise and check the answer in file ‘Comp-R-Ans-to-exer’ in the accompanying CD.

Exercise 2

Acid rain has a pH below 5.6 due mainly to the reaction of water vapor with sulfur dioxide and the oxides of nitrogen. Oxides of nitrogen, particularly nitrogen dioxide (NO₂) react with water to form nitrous acid (HNO₂) and nitric acid (HNO₃):

\[ 2\text{NO}_2(g) + \text{H}_2\text{O(l)} \rightarrow \text{HNO}_2(aq) + \text{HNO}_3(aq) \]

What masses of rain water and NO₂ should react to form 277.2 g of HNO₃?

Hint: Use your general chemistry knowledge on stoicheometry.

2.2.4 Air Pollution and Ozone Depletion

The lower portion of the stratosphere from approximately 15 km to 35 km above Earth’s surface contains high concentration, over 90%, of the ozone (O₃) in earth’s atmosphere. This part of the Earth’s atmosphere is known as the ozone layer. Nearly all, 97-99%, of the sun’s high frequency UV-radiation which is potentially damaging to life on Earth is absorbed in this layer.

Several pollutants attack the ozone layer. However, chlorofluorocarbons (CFCs) are known to be chief among them. CFC molecules are stable, virtually indestructible until they reach the stratosphere. Here, the CFC molecules are broken apart by intense ultraviolet radiation and release the chlorine atoms they contain. These chlorine atoms react with ozone and break it down into ordinary oxygen molecules that do not absorb UV-radiation.
\[ \text{CF}_2\text{Cl}_2 + h\nu \rightarrow \text{Cl}^+ + \text{CCl}_2\text{F}^- \]

\[ \text{Cl}^- + \text{O}_3 \rightarrow \text{ClO}^- + \text{O}_2 \]

\[ \text{ClO}^- + \text{O} \rightarrow \text{Cl}^- + \text{O}_2 \]

**Net Reaction:** \[ 2\text{O}_3 \rightarrow 3\text{O}_2 \]

The chlorine acts as a catalyst. Chlorine takes part in several chemical reactions—yet at the end emerges unchanged and able to react again. Therefore, it acts as a catalyst. A single chlorine atom can destroy up to 100,000 ozone molecules in the stratosphere. In addition to CFCs, other pollutants, such as nitrous oxide from fertilizers and the pesticide methyl bromide, also attack atmospheric ozone. Scientists are finding that under this assault the protective ozone layer in the stratosphere is thinning.

### 2.2.5 Global Warming

At present, our Earth appears to be facing a rapid warming, which most scientists believe results, at least in part, from human activities. Such an increase in the average temperature of the atmosphere, oceans, and landmasses of Earth in general is known as Global warming.

**What are the reasons?**

The energy that lights and warms Earth comes from the Sun. Most of this energy comes as short-wave radiation. Earth’s surface, in turn, releases some of this heat as long-wave infrared radiation. Much of the emitted infrared radiation goes back out to space, but a portion remains trapped in Earth’s atmosphere. Certain gases in the atmosphere, including water vapor, carbon dioxide, and methane, provide the trap. Absorbing and reflecting infrared waves radiated by Earth, these gases conserve heat as the glass in a greenhouse does and are thus known as greenhouse gases. As the atmosphere becomes richer in these gases, it becomes a better insulator, retaining more of the heat provided to the planet by the Sun. The net result; more heat is received from the sun than is lost back to space, a phenomenon known as “greenhouse effect”.

Because of this green house effect, the average surface temperature of the Earth is maintained at a relatively comfortable 15°C. Was this not the case, the surface temperature would average around -18°C. The problem with global warming is that man is adding to and changing the levels of the greenhouse gases and is therefore enhancing this warming.
Carbon dioxide (CO$_2$) is the gas most significantly enhancing the greenhouse effect. Plant respiration and decomposition of organic material release more than 10 times the CO$_2$ than released by human activities, but these have generally been in balance before the industrial revolution. Since the industrial revolution amounts have increased drastically due to combustion of fossil fuel (oil, natural gas and coal) by heavy industry and other human activities, such as transport and deforestation.

Other factors slow the warming, but not to the same degree.

What are the effects?

i) The world is expected to have a more extreme weather, with more rain during wet periods, longer droughts, and more powerful storms.

ii) Melting of the polar ice caps, leading to a rise in sea level. Such a rise would flood coastal cities, force people to abandon low-lying islands, and completely inundate coastal wetlands. Diseases like malaria may become more common in the regions of the globe between the tropics and the polar regions, called the temperate zones.

iii) Climate change may bring extinction for many of the world’s plant species, and for animal species that are not easily able to shift their territories as their habitat grows warmer.

2.2.6 Solving the Problem

What can be done about acid rain and other forms of air pollution? Several options are available, including

- the use of alternative energy sources,
- removal of pollutants from the products of combustion,
- improvement in the efficiency of the combustion process itself, and
- energy conservation.

We will look briefly at the first two, which make use of chemicals and chemical processes.

There are several alternative energy sources for motor vehicles. Of these, natural gas is particularly appealing because of its small potential for air pollution. This fuel contains few sulfur impurities; it burns cleanly with little formation of sulfur or nitrogen oxides. While electric cars powered by batteries might seem to be a completely pollution-free alternative, their use might only shift environmental concerns from one source or location to another. After all, if we switched from the internal combustion engine

Fig 2.5 Gases from Industrial emission
to electric batteries as a source of power, the total quantity of energy now provided by gasoline, diesel fuel, and similar refinery products would have to be replaced by an equivalent quantity of electricity, which would be needed to recharge the newly introduced transportation batteries. The burden of producing this additional quantity of electricity would have to be taken up by existing or new electric power generators, which would in itself introduce new environmental concerns.

Cars and other vehicles account for less than half of the total emissions of SO\textsubscript{x} and NO\textsubscript{x} (but most of the CO) in the United States. Electric utilities and other stationary facilities produce the majority of these pollutants. While these plants might be designed to use alternative energy sources, perhaps including nuclear power, more practical or more immediate approaches include improving the efficiency of the combustion process itself and removing pollutants from exhaust gases before they reach the atmosphere.

Several different approaches are used to reduce pollutants in industrial exhausts, including **electrostatic precipitation, filtration, and scrubbing**. Electrostatic precipitation removes particulates and aerosols, which are small particles of liquids and solids dispersed in smoke. (Smaller particles, less than $10^{-3}$ mm in diameter, make up the aerosols; the larger particles are the particulates). Exhaust gases pass between two charged vertical plates or electrodes. The particles pick up electrons supplied by the negative electrode and move to the more positive one. There the liquid particles accumulate and flow the bottom of the collector; with agitation the solid particles drop off.

### 2.3 Formative Assessment

1. Which of the following disciplines studies the chemistry of the earth’s atmosphere?
   a) Earth chemistry  
   b) Atmospheric chemistry  
   c) Global warming chemistry  
   d) Acid rain chemistry

2. An environmental problem which atmospheric chemistry does not addressed is
   a) acid mine water  
   b) acid rain  
   c) photochemical smog  
   d) global warming

3. Which of the following is not affected by air pollution?
   a) Aquatic animals  
   b) Crops  
   c) Ecosystem  
   d) None
4. The largest gaseous component of the atmosphere is
   a) oxygen     b) carbondioxide      c) nitrogen      d) watervapour

5. Ozone is
   a) desirable in the troposphere
   b) an undesirable pollutant in the stratosphere
   c) filters harmful UV-radiation in the stratosphere
   d) none

6. Which of the following characteristics of the atmosphere is crucial in protecting life on earth?
   a) Reducing temperature extremes between day and night.
   b) Acid-base neutralization reactions taking place in the troposphere
   c) Existence of O_3 in the troposphere
   d) Production of O_2 by plants

7. Which of the following is true about atmospheric pressure?
   a) Atmospheric pressure increases when one progresses from troposphere to stratosphere
   b) Atmospheric pressure decreases in a regular way as one progresses from lower to higher altitudes
   c) Atmospheric pressure increases in a regular way at higher altitudes
   d) None

8. Harmful UV-radiation is blocked by ozone layer in the
   a) mesosphere    b) troposphere   c) stratosphere   d) thermosphere

9. The high temperature in the thermosphere is due to
   a) existence of larger concentration of gaseous molecules which can absorb radiant energy than the other layers.
   b) the absorption of intense solar radiation by oxygen molecules (O_2).
   c) the absorption of intense UV-radiation by ozone
   d) all
10. Free radicals are highly reactive due to the reason that
   a) they are free to move in the atmosphere
   b) the unpaired electron of a free radical has a strong tendency of pairing.
   c) they contain oxygen and hydrogen atoms which are highly reactive
   d) a & b

11. Which of the following atmospheric species is not an unstable species?
   a) Electronically excited molecules
   b) free radicals
   c) ions having electrically-charged atoms
   d) None

12. The most important reactive intermediate of daytime atmospheric chemical phenomena is
   a) O•          b) HO•            c) H₃C•           d) HOO•

13. The reaction, H₂O + hv → HO• + H, represents
   a) the formation of hydroxyl radical at higher altitudes
   b) formation of the hydroxyl radical in the relatively unpolluted troposphere.
   c) the strong reactivity of the hydroxyl radical.
   d) destruction of the hydroxyl radical at higher altitudes

14. Which of the following reactions does not represent removal of the hydroxyl radical from the troposphere?
   a) CO + HO• → CO₂ + H
   b) CH₄ + HO• → H₃C• + H₂O
   c) NH₄ + HO• → H₂N• + H₂O
   d) a & b

15. The atmosphere is slightly acidic because of
   a) the presence of a low level of carbon dioxide
   b) the existence of high amount of nitrogen
   c) the formation of hydrochloric acid by the dissolution of chlorine gas in water
   d) the presence of low level of ammonia.
16. The most important basic species in the atmosphere is
   a) gas phase carbon monoxide
   b) gas-phase ammonia, NH$_3$
   c) Calcium carbonate
   d) Calcium oxide.

17. A highly energetic chemical reaction between three oxygen atoms may produce
   a) ozone molecule and oxygen radical
   b) molecular oxygen and excited oxygen atom
   c) ozone molecule
   d) all

18. At altitudes exceeding above 80 km, the average molecular weight of air is lower than the 28.97 g/mol observed at sea level. Which of the following reasons can be a reason for this fact?
   a) The air in the upper atmosphere is rarefied
   b) Atomic oxygen is stable in the upper atmosphere while it forms molecular oxygen in the lower atmosphere
   c) Gaseous atoms and molecules are heavier in the upper atmosphere than in the lower atmosphere.
   d) All

19. The heterosphere is layer of the atmosphere
   a) that does not contain oxygen atoms
   b) having uniform molecular weight of air
   c) where excess molecular oxygen exists
   d) none

20. Air pollutants which are emitted directly into the atmosphere from an identifiable source are said to be
   a) primary pollutants  c) VOCs
   b) Aerosols          d) all
Answers

1.  b) Atmospheric chemistry
2.  a) acid mine water
3.  d) None
4.  c) nitrogen
5.  c) filters harmful UV-radiation in the stratosphere
6.  a) Reducing temperature extremes between day and night.
7.  b) Atmospheric pressure decreases in a regular way as one progresses from lower to higher altitudes
8.  c) stratosphere
9.  b) the absorption of intense solar radiation by oxygen molecules (O$_2$).
10. b) the unpaired electron of a free radical has a strong tendency of pairing.
11. d) None
12. b) HO•
13. a) the formation of hydroxyl radical at higher altitudes
14. c) NH$_4$ + HO• $\rightarrow$ H$_3$N• + H$_2$O
15. a) the presence of a low level of carbon dioxide
16. b) gas-phase ammonia, NH$_3$.
17. b) molecular oxygen and excited oxygen atom
18. b) Atomic oxygen is stable in the upper atmosphere while it forms molecular oxygen in the lower atmosphere
19. d) none
20. a) primary pollutants
Learning activity 3

Aquatic Chemistry and Water Pollution

Lake Tana (Ethiopia)       A dry river in central Ethiopia

“When the well’s dry, we know the worth of water”

Summary of the Learning Activity

In this learning activity, the various chemical and physical properties of water that make it unique from other liquids and the importance of these properties in the ecological environment are described. The chemical reactions taking place in water bodies, the changes occurring to the form of chemicals in solution and how acidity and complexation control the distribution and fate of chemicals in the aquatic environment are dealt in depth.

Water pollution and the parameters used to define the quality of water, the nature and types of water pollutants and the way they enter water bodies, water quality requirements for different purposes and water pollution control are also described.

Therefore, at the end of this learning activity you should be enable to:

• discuss the various properties of water that make it unique than other liquids
• Define acidity and alkalinity
• Differentiate between alkalinity and basicity
• Calculate the alkalinity of a water body given the required information on the concentrations of CO$_3^{2-}$, HCO$_3^-$ and pH
• define complexation reactions, stability of complexes and formation constant
• Calculate the equilibrium concentrations of species involved in complexation reactions in water bodies.
• Describe the physical and chemical parameters used to describe water quality
List of Relevant Readings


Water Pollution and Society,  
http://www.umich.edu/~gs265/society/waterpollution.htm

Environmental Issues,  
http://www.elmhurst.edu/~chm/vchembook/index.html

Water Structure and Behavior,  
http://textbookrevolution.org/chemistry/water-structure-and-behavior

List of Relevant resources

Computer with internet facility to access links and relevant copy write free resources.

CD-Rom accompanying this module for supplemental readings and to check the answers for the exercises given in the learning activity.

List of Relevant Useful Links

Water Resources, Wastewater Treatment, in VIRTUAL CHEMBOOK, at  
http://www.elmhurst.edu/~chm/vchembook/index.html

Aquatic Chemistry in Resources for Chemistry Educators, Digital Texts, at  
http://www.chem1.com/chemed/digtexts.shtml

This link provides detailed discussions on Acid-base chemistry of natural aquatic systems, Carbonate Equilibria in Natural Waters, and carbonate-CO₂ system;

Water Structure and Science, at http://www.lsbu.ac.uk/water/index2.html  
Provides a detailed discussion on a number of properties of water which make it unique than other liquids.
Unit III  Aquatic chemistry and Water pollution (35 hrs)

Aquatic Chemistry

- Properties of water
- Chemical Reactions in Water Bodies
- Dissolved gases in water
- Acid-base phenomena in water
- Complexation Reactions in Water

Water Pollution

- Water Quality
- Nature and types of water pollutants
- Characterization of Waste Waters
- Water Pollution Control
- Water quality requirements

3.1 Aquatic Chemistry

Exercise 1

Before you start reading the contents of this sub-unit, try to give your comments on the following questions which are related to the unique properties of water. You will appreciate how these properties are vital for the existence of life on our planet.

After writing your comments read the note given in the word file ‘Comp-R-Ans-to-Exer’ in the accompanying CD.

Comment on the significance of the following properties of water for the existence of life and the resulting consequence had water have not that property.

1. The difference in the melting and boiling point temperatures of water is larger than that of many other liquids (100 °C). What would have been the consequence, on living things in general, had this not been the case?

2. Unlike other liquids water becomes lighter when it freezes. What is the advantage of this phenomenon on aquatic life?

3. The heat of vaporization of water is extremely large. What is the significance of this phenomenon on the global weather?

4. Water is able to dissolve more number of substances than any other liquid. What is the significance of this phenomenon of water for plant and animal nutrition?
3.1.1 Properties of Water

Water is a vitally important substance in all parts of the environment. It covers about 70% of Earth’s surface and occurs in all spheres of the environment. It is an essential part of all living systems. Water carries energy and matter through various spheres of the environment. It carries plant nutrients from soil into the bodies of plants by way of plant roots.

The properties of water would best be understood by considering the structure and bonding of the water molecule.

![A dipolar water molecule](image1)

**Fig. 3.1** A dipolar water molecule

A single water molecule we have two hydrogen atoms bonded covalently to an oxygen atom. The three atoms are arranged in a V-shape structure with an angle of 105°. Because of its bent structure and the fact that the oxygen atom attracts electrons more strongly than hydrogen atoms, a water molecule behaves like a dipole having opposite electrical charges at either end. The water dipole may be attracted to either positively or negatively charged ions like with Na⁺ and Cl⁻ during the dissolution of NaCl.

![Dissolution of sodium chloride crystals in water](image2)

**Fig. 3.2** Dissolution of sodium chloride crystals in water
Water has the ability to form hydrogen bonds. **Hydrogen bond** is a special type of bond that can form between the partially positively charged hydrogen atoms in one water molecule and the partially negatively changed oxygen atoms in another water molecule. Hydrogen bond holds water molecules together with strong and also help to hold some solute molecules or ions in solutions.

![Hydrogen bonding between the negative and positive poles of water molecules](image)

**Fig. 3.3** Hydrogen bonding between the negative and positive poles of water molecules

To have a clear understanding of water pollution you should be able to describe the chemical interactions taking place in the large water bodies. In the following section of the module, Chemical Reactions in Water bodies, the solubility of atmospheric gases in open water bodies, chemical reactions that are responsible for the acid–base characteristics of water, complexation reactions and their equilibria, calculations of stability constants and concentrations of species in equilibrium are described. Water pollution and the physical and chemical parameters used to describe pollution, the sources of water pollution and water pollution control are also discussed in brief.

### 3.1.2 Chemical Reactions in Water bodies

Chemical interactions in natural water system are very complex and many variables should be taken into account to describe their chemistry. They are open dynamic systems and have variable inputs and outputs of energy and mass. Therefore, it is difficult to obtain a true equilibrium condition in these kind of systems. Because of this, such systems are frequently described by simplified models. Such models can give us useful generalizations and insights of the nature of aquatic chemical processes, and provide guidelines for the description and measurement of natural water systems. Fig 3.5 is one such model that illustrates the main categories of aquatic chemical phenomena.
3.1.2.1. Dissolved Gases in Water

Natural water systems contain a number of gases dissolved in them. Among these gases $O_2$ and $CO_2$ are vital for aquatic animals and plants. For example $O_2$ is essential for fish and $CO_2$ for photosynthetic algae. Some gases in water can also cause problems, such as the death of fish from bubbles of nitrogen formed in the blood.

A) Oxygen in Water

Most of the elemental oxygen that we find dissolved in water comes from the atmosphere and also from the photosynthetic action of algae. As many kinds of aquatic organisms require oxygen for their existence, water bodies should contain appreciable level of dissolved oxygen.

Dissolved oxygen can decrease due to different reasons. Part of the oxygen coming from algal photosynthesis during the day for example is used up by the algae itself as part of their metabolic processes. Because of this, dissolved oxygen contribution through algal photosynthesis is not that efficient. The degradation of biomass coming from dead algae and other organic matter also consume dissolved oxygen. Therefore, the ability of a body of water to reoxygenate itself by contact with the atmosphere is an important characteristic.
B) Carbon Dioxide in Water

Carbon dioxide is present in virtually all natural waters and wastewaters and is the most important weak acid in water. The CO₂ in water comes from the dissolution of atmospheric CO₂ and from microbial decay of organic matter. Carbon dioxide and its ionization products have extremely important influence upon the chemistry of water. Many minerals are deposited as salts of the carbonate ion.

Although dissolved CO₂ is often represented as H₂CO₃, just a small fraction of the dissolved CO₂ is actually present as H₂CO₃. Therefore, to make a distinction, nonionized carbon dioxide in water is designated simply as CO₂.

The equilibrium for dissolution of CO₂ in water is represented by the following equations

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{H}^+ \quad (3.1)
\]

\[
K_{a1} = \frac{[\text{HCO}_3^-][\text{H}^+]}{[\text{CO}_2]} = 4.45 \times 10^{-7} \quad \text{p}K_{a1} = 6.35 \quad (3.2)
\]

\[
\text{HCO}_3^- \rightleftharpoons \text{CO}_3^{2-} + \text{H}^+ \quad (3.4)
\]

\[
K_{a2} = \frac{[\text{CO}_3^{2-}][\text{H}^+]}{[\text{HCO}_3^-]} = 4.69 \times 10^{-11} \quad \text{p}K_{a2} = 10.33 \quad (3.5)
\]

Therefore, dissolved CO₂ at equilibrium contains: CO₂, bicarbonate ion (HCO₃⁻), and carbonate ion (CO₃²⁻). The predominant species formed by CO₂ dissolved in water depends upon pH. This is best shown by a distribution of species diagram with pH as a master variable as illustrated in Figure 3.6.

From Figure 3.5 we can see that hydrogen carbonate (bicarbonate) ion (HCO₃⁻) is the predominant species in the pH range found in most waters, with CO₂ predominating in more acidic waters.
3.1.3 Acid-base phenomena in water

In your general chemistry courses you have studied the various definitions of acids and bases given by different scientists. In this section, we use the definition given by Bronsted and Lowry. According to the Bronsted - Lowry definition, acids are described as those chemical species that lose H\(^+\) ion in a reaction and bases as those chemical species that accept the H\(^+\) ion lost by acids.

The bicarbonate ion, HCO\(_3\)\(^-\), is an important species in the acid-base chemistry of water. In water, it may act as either an acid or a base:

\[
\text{HCO}_3^- \leftrightarrow \text{CO}_3^{2-} + \text{H}^+ \quad (\text{HCO}_3^- \text{ acting as an acid}) \quad (3.6)
\]

\[
\text{HCO}_3^- + \text{H}^+ \rightarrow \text{CO}_2 (aq) + \text{H}_2\text{O} \quad (\text{HCO}_3^- \text{ acting as a base}) \quad (3.7)
\]

**Acidity** as applied to natural water and wastewater is the capacity of the water to neutralize OH\(^-\) and **alkalinity** is the capacity to neutralize H\(^+\). Although virtually all water has some alkalinity acidic water is not frequently encountered, except in cases of severe pollution. Existence of weak acids, particularly CO\(_2\), and sometimes H\(_2\)PO\(_4\)\(^-\), H\(_2\)S, proteins, and fatty acids is in general the reason for water acidity. Acidic metal ions, such as Fe\(^{3+}\), may also contribute to water acidity. The acidic character of some hydrated metal ions such as Al(H\(_2\)O\(_6\))\(^{3+}\) may also contribute to water acidity:

\[
\text{Al(H}_2\text{O)}_{6}^{3+} \rightarrow \text{Al(H}_2\text{O)}_{5}\text{OH}^{2-} + \text{H}^+ \quad (3.8)
\]

Alkalinity is important in water treatment and in the chemistry and biology of natural waters. In water treatment, we frequently need to know the alkalinity of water to calculate the quantities of chemicals to be added. Water which is highly alkaline often has a high pH and generally contains elevated levels of dissolved solids which make it unsuitable to be used in boilers, food processing, and municipal water systems.

Alkalinity serves as a pH buffer and reservoir for inorganic carbon, thus helping to determine the ability of water to support algal growth and other aquatic life, so it can be used as a measure of water fertility. In general, bicarbonate ion, carbonate ion, and hydroxide ion are the basic species responsible for water alkalinity (See the reactions below).

\[
\text{HCO}_3^- + \text{H}^+ \rightarrow \text{CO}_2 + \text{H}_2\text{O} \quad (3.9)
\]

\[
\text{CO}_3^{2-} + \text{H}^+ \rightarrow \text{HCO}_3^- \quad (3.10)
\]

\[
\text{OH}^- + \text{H}^+ \rightarrow \text{H}_2\text{O} \quad (3.11)
\]

Alkalinity may be expressed as either **phenolphthalein (bicarbonate) alkalinity** or **total alkalinity**. Phenolphthalein alkalinity, is determined by titrating the water with acid to the pH at which HCO\(_3\)\(^-\) is the predominant carbonate species (pH 8.3), while total alkalinity, is determined by titrating with acid to the methylorange endpoint (pH
4.3), where both bicarbonate and carbonate species will be converted to CO\(_2\). In total alkalinity calculation for water below pH 7, the H\(^+\) concentration in the water must be subtracted since its concentration will be significantly high. In a medium where the only contributors to alkalinity are HCO\(_3\)\(^-\), CO\(_3\)\(^2-\), and OH\(^-\), alkalinity is calculated by using the following equation.

\[
[\text{alk}] = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{OH}^-] - [\text{H}^+] \quad (3.12)
\]

The concentration of CO\(_3\)\(^2-\) is multiplied by 2 because each CO\(_3\)\(^2-\) ion can neutralize 2 H\(^+\) ions.

Alkalinity is given as Mol H\(^+\)/L or Equivalents/L or mg/L of CaCO\(_3\), based upon the acid-neutralizing reaction: CaCO\(_3\) + 2H\(^+\) \rightarrow Ca\(^{2+}\) + CO\(_2\) + H\(_2\)O.

Natural water typically has an alkalinity, designated here as “[alk]” of 1.00 x 10\(^{-3}\) equivalents per liter (eq/L), meaning that the alkaline solutes in 1 liter of the water will neutralize 1.00 x 10\(^{-3}\) moles of acid.

**Example:** The alkalinity of a river was determined to be 5 x 10\(^{-3}\) mol H\(^+\)/L and its pH is 8.0. Calculate the concentrations of CO\(_3\)\(^2-\) and HCO\(_3\)\(^-\) in the river.

**Solution:**

Using the given pH value we can calculate [H\(^+\)] and [OH\(^-\)]

\[
\text{pH} = -\log [\text{H}^+] \quad 8 = -\log [\text{H}^+] \quad [\text{H}^+] = 10^{-8}
\]

\[
\text{Kw} = [\text{H}^+] [\text{OH}^-] = 10^{-14} \quad [\text{OH}^-] = \frac{10^{-14}}{10^{-8}} = 10^{-6}
\]

Replacing the values of the concentrations of H\(^+\) and OH\(^-\) in the alkalinity equation we will have

\[
[\text{alk}] = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + 10^{-6} - 10^{-8}
\]

From the equation for the second dissociation constant of H\(_2\)CO\(_3\) we can calculate the concentration of HCO\(_3\)\(^-\) in terms of that of CO\(_3\)\(^2-\).
\[ \text{HCO}_3^- \rightleftharpoons \text{CO}_3^{2-} + \text{H}^+ \]

\[ K_a = \frac{[\text{CO}_3^{2-}] [\text{H}^+]}{[\text{HCO}_3^-]} = 4.69 \times 10^{-11} \]

\[ \Rightarrow [\text{HCO}_3^-] = \frac{[\text{CO}_3^{2-}] \times 10^{-8}}{4.69 \times 10^{-11}} \]

\[ \Rightarrow [\text{HCO}_3^-] = 213.22 [\text{CO}_3^{2-}] \]

Replacing 213.22 [\text{CO}_3^{2-}] in place of [\text{HCO}_3^-] we have

\[ [\text{alk}] = 213.22 [\text{CO}_3^{2-}] + 2[\text{CO}_3^{2-}] + 10^{-6} - 10^{-8} \]

\[ \Rightarrow 5 \times 10^{-3} = 213.22 \times [\text{CO}_3^{2-}] + 2[\text{CO}_3^{2-}] + 10^{-6} - 10^{-8} \]

\[ 215.22 [\text{CO}_3^{2-}] = 5 \times 10^{-3} \]

\[ [\text{CO}_3^{2-}] = \frac{5 \times 10^{-3}}{215.22} = 2.3 \times 10^{-5} \]

\[ [\text{HCO}_3^-] = 213.22 \times [\text{CO}_3^{2-}] = 213.22 \times 2.3 \times 10^{-5} = 4.95 \times 10^{-3} \]

Note that basicity is different from alkalinity. Basicity is an intensity factor indicating pH value (high basicity \( \Rightarrow \) high pH value; low basicity indicates low pH); whereas alkalinity is a capacity factor indicating the capacity to accept \( \text{H}^+ \). Consider a solution of 1.00 \( \times \) \( 10^{-3} \) M NaOH and a solution of 0.100 M H\text{CO}_3^-\text{.} \) The sodium hydroxide solution is quite basic, with a pH of 11, but a liter of it will neutralize only 1.00 \( \times \) \( 10^{-3} \) mole of acid. The pH of the sodium bicarbonate solution is 8.34, much lower than that of the NaOH. However, a liter of the sodium bicarbonate solution will neutralize 0.100 mole of acid; therefore, its alkalinity is 100 times that of the more basic NaOH solution.

\textbf{Note:} Try to workout the following exercise and check your answer in the file \textit{Comp-R-Ans-to-exer} in the accompanying CD.

\section*{Exercise 2}

The pH expected for a body of water in equilibrium with the atmosphere, and does not contain limestone is acidic. Explain why the pH of most water bodies which contain limestone, Ca\text{CO}_3\text{, are alkaline.}
3.1.4 Complexation reactions in water

Water contains different kinds of metal ions that exist in numerous forms. Unpolluted waters and biological systems contain the metal ions: Mg$^{2+}$, Ca$^{2+}$, Mn$^{2+}$, Fe$^{2+}$, Fe$^{3+}$, Cu$^{2+}$, Zn$^{2+}$, VO$^{2+}$ and metal ions such as Co$^{2+}$, Ni$^{2+}$, Sr$^{2+}$, Cd$^{2+}$, and Ba$^{2+}$ exist in contaminated water.

All metal ions in water exist bonded, or coordinated to other species such as water or other stronger bases that might be present in the water. Metals may also exist in water reversibly bound to inorganic anions or to organic compounds as metal complexes. For example, a cyanide ion can bond to dissolved iron(II) by donating a pair of electrons:

$$\text{Fe(H}_2\text{O)}_6^{2+} + \text{CN}^- \rightleftharpoons \text{FeCN(H}_2\text{O)}_5^{2+} + \text{H}_2\text{O} \quad (3.13)$$

One of the water molecules in Fe(H$_2$O)$_6^{2+}$ is replaced by a cyanide ion to form FeCN(H$_2$O)$_5^{2+}$. Additional cyanide ions may replace the remaining water molecules to form Fe(CN)$_2$(H$_2$O)$_4$, Fe(CN)$_3$(H$_2$O)$_3^-$, Fe(CN)$_4$(H$_2$O)$_2^{2-}$, Fe(CN)$_5$(H$_2$O)$_3^{-}$, and Fe(CN)$_6^{4-}$. The kind of reaction that has taken place between the CN$^-$ ions and hydrated Fe$^{2+}$ is called complexation. The product of the reaction, FeCN(H$_2$O)$_5^{2+}$ in the above equation, is known as a complex, complex ion, or coordination compound. The species that donates the pair of electrons to the central metal ion, CN$^-$ in the example above, is called a ligand. In the example above, the cyanide ion donates a single pair of electrons or it possesses only one site that bonds to a metal ion, and is known as a unidentate ligand. There are ligands that possess more than one sight (more than one atom) to form a bond with a metal ion. Such ligands form ring structured complexes and are known as chelating agents. The species formed are known as chelates. Chelating agents are common potential water pollutants. They occur in sewage effluent and industrial wastewater such as metal plating wastewater.

Complexation may have a number of effects in water. It may cause changes in the oxidation state of a metal ion and may result in the formation of a more soluble form of the metal from an insoluble compound. Insoluble complex compounds remove metal ions from solution. Because of their ability to solubilize heavy metals from plumbing, and from deposits containing heavy metals complexing agents are of primarily concern in wastewater. Complexation may increase the leaching of heavy metals from waste disposal sites and reduce the efficiency with which heavy metals are removed with sludge in conventional biological waste treatment.
3.1.4.1 Stability of Complexes

The formation of a metal–ligand complex is described by a **formation constant**, \( K_f \). The value of the formation constant expresses the stability of the complex. The formation constant for the complexation reaction between \( \text{Cd}^{2+} \) and \( \text{NH}_3 \), for example, is given by

\[
K_f = \frac{[\text{Cd}(<\text{NH}_3>)_{2+}]}{[\text{Cd}^{2+}][\text{NH}_3]^4} = 5.5 \times 10^7
\]  

(3.14)

The complexation reaction between \( \text{Cd}^{2+} \) and \( \text{NH}_3 \), including many others occur in a stepwise fashion. For example, the reaction between \( \text{Cd}^{2+} \) and \( \text{NH}_3 \) involves four successive reactions which are shown by the equations given below.

\[
\text{Cd}^{2+}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{Cd}(<\text{NH}_3>)_{2+}(aq) \tag{3.15}
\]

\[
\text{Cd}(<\text{NH}_3>)_{2+}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{Cd}(<\text{NH}_3>)_{3+}(aq) \tag{3.16}
\]

\[
\text{Cd}(<\text{NH}_3>)_{3+}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{Cd}(<\text{NH}_3>)_{4+}(aq) \tag{3.17}
\]

\[
\text{Cd}(<\text{NH}_3>)_{4+}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{Cd}(<\text{NH}_3>)_{5+}(aq) \tag{3.18}
\]

Since it is not clear what reaction is described by a formation constant the above successive reactions create a problem. To avoid this, formation constants are divided into stepwise formation constants and cumulative or overall formation constants.

**Stepwise formation constants**, designated as \( K_i \) for the \( i \)th step, describe the successive addition of a ligand to the metal–ligand complex formed in the previous step and **overall**, or **cumulative formation constants**, which are designated as \( \beta_i \), describe the addition of \( i \) ligands to the free metal ion. Thus, the equilibrium constants for reactions 3.15 - 3.18 are, respectively, \( K1, K2, K3, \) and \( K4 \). The formation constant expressions for each of the steps are given by equations 3.19 – 3.22.

\[
\text{Cd}^{2+}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{Cd}(<\text{NH}_3>)_{2+}(aq) \tag{3.19}
\]

\[
K1 = \frac{[\text{Cd}(<\text{NH}_3>)_{2+}]}{[\text{Cd}^{2+}][\text{NH}_3]} \tag{3.20}
\]

\[
\text{Cd}(<\text{NH}_3>)_{2+}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{Cd}(<\text{NH}_3>)_{3+}(aq) \tag{3.16}
\]

\[
K2 = \frac{[\text{Cd}(<\text{NH}_3>)_{3+}]}{[\text{Cd}(<\text{NH}_3>)_{2+}][\text{NH}_3]} \tag{3.21}
\]

\[
\text{Cd}(<\text{NH}_3>)_{3+}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{Cd}(<\text{NH}_3>)_{4+}(aq) \tag{3.17}
\]

\[
K3 = \frac{[\text{Cd}(<\text{NH}_3>)_{4+}]}{[\text{Cd}(<\text{NH}_3>)_{3+}][\text{NH}_3]} \tag{3.22}
\]
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\[
\text{Cd(NH}_3\text{)}_{\text{3}}^{2+}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{Cd(NH}_3\text{)}_{\text{4}}^{2+}(aq)
\]

\[
K_4 = \frac{[\text{Cd(NH}_3\text{)}_{\text{4}}^{2+}]}{[\text{Cd(NH}_3\text{)}_{\text{3}}^{2+}][\text{NH}_3]} \quad (3.22)
\]

The equilibrium constant expression given in equation 3.14, therefore, is correctly identified as \( \beta_4 \), where

\[
\beta_4 = K_1 \times K_2 \times K_3 \times K_4
\]

In general \( \beta_i = K_1 \times K_2 \times K_3 \times \ldots \times K_i \)

The formation constant given in 3.14, for example, is given by

\[
\beta_4 = \frac{[\text{Cd(NH}_3\text{)}_{\text{4}}^{2+}]}{[\text{Cd}^{2+}][\text{NH}_3]^4} = 5.5 \times 10^7 \quad (3.23)
\]

At pH values of 11 or above, EDTA is essentially all in the completely ionized tetranegative form, \( Y^{4-} \), illustrated below:

Of the several complexing agents found in water is ethylenediamineotetraacetic acid (EDTA). Most metals are known to form chelates with EDTA. It has the structure given below

\[
\text{HOOC} - \text{CH}_2 \quad \text{N} - \text{CH}_2 - \text{CH}_2 - \text{N} \quad \text{CH}_2 - \text{COOH}
\]

EDTA contains four replaceable hydrogen atoms and depending on the pH it contains \( H_4Y, H_3Y, H_2Y^{2-}, HY^{-}, \) and \( Y^{4-} \) in different proportions. In water, metal ions and hydrogen ions compete for \( Y^{4-} \). At lower pH values, the protonated forms of EDTA dominate the unprotonated forms while as pH increases, the fraction of free \( Y^{4-} \) that can be complexed to metal ions increases. At pH values of 11 or above, EDTA is essentially all in the completely ionized tetranegative form, \( Y^{4-} \).
**Example:** Copper reacts with EDTA to form CuY\(^{2-}\) according to the reaction

\[
\text{Cu}^{2+} + \text{Y}^{4-} \rightleftharpoons \text{CuY}^{2-} \quad K_1 = 6.3 \times 10^{18}
\]

A wastewater was analyzed to determine the relative amount of EDTA-complexed copper and free uncomplexed copper and the following results were obtained:

- pH = 11
- Total Cu(II) = 5.0 mg/L
- Excess free EDTA = 200 mg/L (expressed as the disodium salt, Na\(_4\)H\(_2\)C\(_{10}\)H\(_{12}\)O\(_8\)N\(_2\) \cdot 2H\(_2\)O, formula weight 372).

Will most of the copper be present as the EDTA complex or in the uncomplexed form?

Calculate the equilibrium concentration of the hydrated copper(II) ion, Cu\(^{2+}\)?

**Solution**

At pH 11, uncomplexed EDTA exists as Y\(^{4-}\). Its molar concentration, [Y\(^{4-}\)] is given by

\[
[Y^{4-}] = \frac{0.2 \text{ g L}^{-1}}{372 \text{ g mol}^{-1}} = 5.4 \times 10^{-4}
\]

The formation constant for the reaction, Cu\(^{2+}\) + Y\(^{4-}\) \rightleftharpoons CuY\(^{2-}\), is given by

\[
K_1 = \frac{[\text{CuY}^{2-}]}{[\text{Y}^{4-}][\text{Cu}^{2+}]} = 6.3 \times 10^{18}
\]

From this equation, the ratio of complexed copper to the uncomplexed will be

\[
\frac{[\text{CuY}^{2-}]}{[\text{Cu}^{2+}]} = 6.3 \times 10^{18} \times \frac{[Y^{4-}]}{[\text{Cu}^{2+}]}
\]

Replacing 5.4 \times 10^{-4} for [Y\(^{4-}\)] we have,

\[
\frac{[\text{CuY}^{2-}]}{[\text{Cu}^{2+}]} = \frac{6.3 \times 10^{18} \times 5.4 \times 10^{-4}}{[\text{Cu}^{2+}]} = 3.4 \times 10^{15}
\]

This result indicates that, copper existing as the complex ion is extremely larger than the uncomplexed copper or essentially all of the copper is present as the complex ion.
Self test

Before reading the following sub-topics write a paragraph on what you understand by the statement:

‘The pollution of water is evaluated depending on its intended use!’

and evaluate to what extent you have understood to issue.

3.2 Water Pollution

Of all the resources that we have on our planet water is undoubtedly the most precious. Without it, life on Earth would be non-existent: it is essential for everything on our planet to grow and prosper. Although we recognize this fact, we disregard it by polluting our rivers, lakes, and oceans. Subsequently, we are slowly but surely harming our planet to the point where organisms are dying at a very alarming rate. In addition to innocent organisms dying off, our drinking water has become greatly affected by pollution. In order to combat water pollution, we must understand the problems and become part of the solution.

3.2.1 Water Quality

The quality of water that we use for different purposes in life can be evaluated by using physical and chemical parameters. Quality indicators under both the physical and chemical parameters are described in the following sub-units.

‘The quality of water is evaluated depending on its intended use!’
3.2.1.1 Physical Water Quality Parameters

Physical parameters define those characteristics of water that respond to the sense of sight, touch, taste or smell. Suspended solids, turbidity, color, taste and odor, and temperature fall in this category.

A) Suspended solids - Sources and impacts

Solids can be dispersed in water in both suspended and dissolved forms. Although some dissolved solids may be perceived by the physical sense, they fall more approximately under the category of chemical parameters.

Solids suspended in water may consist of inorganic substances such as clay and silt or organic particles such as plant fibers, algal and bacterial remains. Because of the filtering capacity of the soil, suspended material is seldom a constituent of ground water.

Other suspended material may also result from

- human use of the water.
- Industrial use

Domestic wastewater usually contains large quantities of suspended solids that are mostly organic in nature.

Suspended materials in water make the water aesthetically unpleasant and provide adsorption sites for chemical and biological agents. Biological degradation of suspended organic solids results in objectionable by-products. Biologically active (live) suspended solids may include disease causing organisms as well as organisms such as toxin-producing strains of algae.

Suspended solids could be divided into filterable residues and non-filterable residues.

Suspended solids, where such material is likely to be organic and/or biological in nature, are important parameter of wastewater. The suspended-solids parameter is used to measure the quality of the wastewater affluent, to monitor several treatment processes, and to measure the quality of the effluent. EPA has set a maximum suspended-solids standard of 30 mg/L for most treated wastewater discharges.
B) Turbidity: Sources and impacts

Turbidity is the measure of the extent to which light is either absorbed or scattered by suspended particles in water. Absorption and scattering are known to be influenced by both the size and surface characteristics of the suspended material. Therefore, turbidity can not be a direct quantitative measure of suspended solids. For example, a small pebble in a glass of water would not produce any turbidity. However, if this pebble were crushed into small particles of colloidal size it produces a measurable amount of turbidity although the mass of the pebble will not change.

Turbidity in surface waters results from soil erosion. Household and industrial wastewaters such as soaps, detergents and emulsifying agents produce stable colloids that result in turbidity.

Impacts

Turbidity makes drinking water aesthetically displeasing and the colloidal materials associated with turbidity provide adsorption sites for chemicals that may be harmful or cause undesirable tastes and odors and for biological organisms that may be harmful to health.

C) Color and its sources

Pure water has no color. However, due to foreign materials natural water is often colored. The tannins, humic acid, and humates taken up by water from filterable suspended organic debris such as leaves, weeds, or wood, impart yellowish-brown color to water. Non-filterable substances such as iron oxides cause reddish water. Industrial wastes from textile and dyeing operations, pulp and paper production, food processing, chemical production, and mining, refining, and slaughterhouse operations may add substantial coloration to water in receiving streams. In general part of the water coloration coming from filterable suspended matter is said to be apparent color and that contributed by dissolved solids, which remain after removal of filterable suspended matter, is known as true color.

Impacts

Similar to turbid water, colored water is aesthetically unacceptable to the general public. Highly colored water is unsuitable for laundering, dyeing, papermaking, beverage manufacturing, and dairy production. Therefore, colored water is less marketable both for domestic and industrial use.
D) Taste and odor

The taste of water is the flavor that water gives us when we put it into our mouth, and the quality of water that we perceive by our sense of smell is its odor. Consumers may attribute a wide variety of tastes and odors to water. Substances that produce odor in water will almost invariably impart a taste as well. However, the converse is not true, as there are many mineral substances that produce taste but not odor. Organic materials or, their biological decomposition, are known to produce both taste and odor problems in water. Principal among these are the reduced products of sulfur that imparts a “rotten egg” odor and taste. Also, certain species of algae secrete an oily substance that may result in both taste and odor. The combination of two or more substances neither of which would produce taste or odor by itself may sometimes result in taste or odor problems. Alkaline mineral imparts a bitter taste to water, while metallic salts may give a salty or bitter taste.

Fig.3.7 Putrified water

Impacts

Taste and odor make water aesthetically displeasing to consumers. Some of the substances that impart bad taste and odor may be carcinogenic.

E) Temperature and its sources

Temperature is not used as a parameter to evaluate potable water or wastewater directly. It is however, one of the most important parameters in natural surface-water systems. The temperature of surface waters governs to a large extent the biological species present and their rates of activity. It also influences most chemical reactions that occur in natural water systems the solubility of gases in water.

Generally, shallow bodies of water are more affected by ambient temperatures (temperature of the surrounding atmosphere) than are deeper bodies. Water used for the dissipation of waste heat in industry and the subsequent discharge of the heated water may result in an increasing in the temperature of receiving streams, though perhaps localized. Removal of forest canopies and irrigation return flows can also result in increased stream temperature.
Impacts

Lower temperatures favor slower rate of biological activity. Provided that essential nutrients are available, biological activity is doubled by an increase of approximately 10 °C. With an increase in metabolic rates, organisms that are efficient at food utilization and reproduction flourish, while other species decline and are perhaps eliminated altogether. Algal growth is often accelerated in warm water and can become a problem when cells cluster into algae mats. Natural secretion of oils by the algae in the mats and the decay products of dead algae cells can result in taste and odor problems. Higher-order species, such as fish, are affected dramatically by temperature and by dissolved oxygen levels, which are a function of temperature. Game fish generally require cooler temperatures and higher dissolved-oxygen levels.

Temperature changes affect the reaction rates and solubility levels of chemicals. Most chemical reactions involving dissolution of solids are accelerated by an increase in temperature. The solubility of gases, on the other hand, decreases at elevated temperatures. Thus, with an increase in temperature the level of dissolved oxygen will decrease. This is undesirable situation since biological oxidation of organics in streams is dependent on adequate supply dissolved oxygen.

3.2.1.2 Chemical water quality parameters

Water has been called the universal solvent, and chemical parameters are related to the solvent capabilities of water. Total dissolved solids, alkalinity hardness, fluorides, metals, organics and nutrients are chemical parameters of concern in water quality management. Readers are kindly advised to review basic chemistry part in order to easily grasp the ideas presented here.

Reading assignment

1. There are a number of man made and nature driven water pollutants. For the ease of study, these water pollutants are classified in different ways depending on their chemical nature, or the set of hazards they present and so on.

   Read the pdf file ‘Comp-R-waterpollutants-andWHO guideline’ and write a summary of the major water pollutants.

2. Waste water, is known to pollute surface and ground water when released untreated.

   Read the pdf file ‘Comp-R-waterpollutants-andWHO guideline’ and answer the following questions.
   
   a) What waste-water and what are its sources?
   b) What are the characteristics of waste-water?
   c) What are the major categories of waste-water treatment?
3. The composition of water varies widely with local geological conditions. No matter how pure it is, water contains small amounts of gases, minerals and organic matter. The definition for the purity of water permits that the water contains different levels of substances depending on the purpose the water is to be used for.

Read the pdf file ‘Comp-R-waterpollutants-andWHO guideline’ and describe why drinking water is required to contain different levels, high, medium, low or very low levels of different substances.

### 3.3 Formative Assessment

1. Which of the following gases is vital for aquatic plants?
   a) $N_2$  
   b) $O_2$  
   c) $CO_2$  
   d) $SO_2$

2. The main source of elemental oxygen that we find dissolved in water comes from
   a) atmospheric oxygen
   b) photosynthetic action of algae
   c) from the auto dissociation of water
   d) all

3. Dissolved oxygen contribution through algal photosynthesis is considered not to be efficient due to the fact that,
   a) it is too small
   b) its solubility is much less than the oxygen coming from the environment
   c) part of this oxygen is used up by the algae itself as part of their metabolic processes
   d) none

4. The degradation of biomass coming from aquatic organic matter
   a) increases dissolved oxygen
   b) decreases dissolved oxygen
   c) does not affect the level of dissolved oxygen
   d) none
5. In the distribution of species diagram for the \( \text{CO}_2 - \text{HCO}_3^- - \text{CO}_3^{2-} \) system in water the species that dominates at higher pH values is
   a) \( \text{H}_2\text{CO}_3 \)  
   b) \( \text{HCO}_3^- \)  
   c) \( \text{CO}_3^{2-} \)  
   d) \( \text{CO}_2 \)

6. As applied to natural water and wastewater acidity is defined as
   a) the capacity of the water to neutralize \( \text{H}^+ \)
   b) the capacity of the water to neutralize \( \text{OH}^- \)
   c) the capacity of the water to donate electrons
   d) the concentration of \( \text{H}^+ \) in water

7. Water which is highly alkaline
   a) has a low pH value
   b) has a high pH value
   c) contains low levels of dissolved solids
   d) a & c

8. The alkalinity of pure water is \( 1.00 \times 10^{-3} \) eq/L. This implies that,
   a) pure water contains \( 1.00 \times 10^{-3} \) equivalents of \( \text{OH}^- \) in one liter.
   b) alkaline solutes in 1 liter of pure water will neutralize \( 1.00 \times 10^{-3} \) moles sulfuric acid
   c) alkaline solutes in 1 liter of pure water will neutralize \( 1.00 \times 10^{-3} \) moles \( \text{H}^+ \)
   d) acidic solutes in 1 liter of pure water will neutralize \( 1.00 \times 10^{-3} \) moles \( \text{OH}^- \)

9. Alkalinity is given by the equation, \([\text{alk}] = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{OH}^-] - [\text{H}^+]\).
   In this equation the reason for doubling the concentration of \( \text{CO}_3^{2-} \) is that,
   a) \( \text{CO}_3^{2-} \) is a very strong alkali
   b) one mole of \( \text{CO}_3^{2-} \) can neutralize 2 moles of \( \text{H}^+ \)
   c) one mole of \( \text{CO}_3^{2-} \) can neutralize 2 moles of \( \text{OH}^- \)
   d) all

10. In the equation for alkalinity, subtracting the concentration of \( \text{H}^+ \) is mainly required while calculating
    a) total alkalinity
    b) phenolphthalein alkalinity
    c) bicarbonate alkalinity
    d) b & c
11. Which of the following is true about basicity and alkalinity?
   a) Alkalinity is an intensity factor indicating pH value
   b) Basicity is an intensity factor indicating pH value
   c) High basicity indicates low pH and low basicity indicates high pH
   d) Alkalinity is a capacity factor indicating the capacity to donate H⁺

12. In the stepwise formation of $\text{Cd(NH}_3)_4^{2+}(aq)$, the equilibrium expression for $K_3$ is given by the equation,

   a) $K_3 = \frac{[\text{Cd(NH}_3)_2^{2+}]}{[\text{NH}_3][\text{Cd(NH}_3)_4^{2+}]}$
   b) $K_3 = \frac{[\text{Cd(NH}_3)_3^{2+}]}{[\text{Cd}^{2+}][\text{NH}_3]}$
   c) $K_3 = \frac{[\text{Cd(NH}_3)_4^{2+}]}{[\text{NH}_3][\text{Cd(NH}_3)_3^{2+}]}$
   d) $K_3 = \frac{[\text{Cd(NH}_3)_4^{2+}]}{[\text{Cd}^{2+}][\text{NH}_3]}$

13. Which of the following describes a reason for the concern about complexing agents in water pollution?
   a) Complexing agents may react with heavy metal pollutants in waste disposal sites and form soluble complexes which are leached into surface or ground water.
   b) Strong complexing agents in water bodies may form more toxic and more stable metal complexes by displacing weaker complexing agents.
   c) Strong complexing agents in water bodies may form less toxic and more stable metal complexes by displacing weaker complexing agents.
   d) all

14. A smaller formation constant of a complex indicates that
   a) the complex is less toxic
   b) the complex is more dissociated
   c) the complex is highly toxic
   d) a & b

15. A given body of water is said to be polluted when it
   a) is not fit for drinking
   b) is not fit for an intended purpose
   c) contains metallic elements
   d) is not pure $\text{H}_2\text{O}$
3.3 Answers to Formative Assessment

1. c) CO₂
2. a) atmospheric oxygen
3. c) part of this oxygen is used up by the algae itself as part of their metabolic processes
4. b) decreases dissolved oxygen
5. c) CO₃²⁻
6. b) the capacity of the water to neutralize OH⁻
7. b) has a high pH value
8. c) alkaline solutes in 1 liter of pure water will neutralize 1.00 x 10⁻³ moles H⁺
9. b) one mole of CO₃²⁻ can neutralize 2 moles of H⁺
10. a) total alkalinity
11. b) Basicity is an intensity factor indicating pH value
12 b) \( K_3 = \frac{[\text{Cd(NH}_3)_3^{2+}]}{[\text{NH}_3][\text{Cd(NH}_3)_2^{2+}]} \)
13. d) all
14. b) the complex is more dissociated
15. b) is not fit for an intended purpose
Learning activity 4

Soil Chemistry and Pollution

Summary of the Learning Activity

This learning activity provides an overview of the mechanisms of soil formation and its composition. The soil horizons and their physical and chemical characteristics, soil pollution and its control are also dealt in brief.

Therefore, at the end of this learning you should be able to

• Discuss the mechanisms of soil formation
• Explain the composition of soils
• Describe the physical and chemical properties of soils
• Explain the chemical characteristics of the various classes of soils
• Discuss soil pollution and its sources
• Explain the ways of controlling soil pollution

List of relevant readings


List of Relevant Useful Links

Environmental Geochemistry,
http://www.ronstoessell.org/environmental_geochemistry.htm#Water_Properties

Soil contamination,
http://en.wikipedia.org/wiki/Soil_contamination

Pollution,
http://en.wikipedia.org/wiki/Pollution
**Soil and the Environment,**
http://soil.gsfc.nasa.gov/env.htm

**Environmental Chemistry,**
http://www.tutorvista.com/content/chemistry/chemistry-iii/environmental-chemistry/environmental-chemistry.php

**Topics covered**

**Unit IV  Soil Chemistry and Pollution (25 hrs)**

Soil Chemistry
- Introduction
- Composition of Soils
- Soil Formation
- Soil Characteristics
- Soil Erosion

Soil Pollution
- Sources of Soil Pollution
- Effects of Soil Pollution
- Control of Soil Pollution

**List of Relevant resources**

Computer with internet facility to access links and relevant copy write free resources.

CD-Rom accompanying this module for supplemental readings and to check the answers for the exercises given in the learning activity.
4.1  Soil Chemistry

4.1.1  Introduction

Soil is a mixture of mineral, plant, and animal materials, that forms during a long process that may take thousands of years. In general, soil is an unconsolidated, or loose, combination of inorganic and organic materials. It is necessary for most plant growth and is essential for all agricultural production. The inorganic components of soil are principally produced by the weathering of rocks and minerals. The organic materials are composed of debris from plants and from the decomposition of the many tiny life forms that inhabit the soil.

The chemical composition and physical structure of soils is determined by a number of factors such as: the kinds of rocks, minerals, and other geologic materials from which the soil is originally formed. The vegetation that grow in the soil are also important.

Food sources grown on soils are predominately composed of carbon, hydrogen, oxygen, phosphorous, nitrogen, potassium, sodium and calcium. Plants take up these elements from the soil and configure them into the plants we recognize as food. Each plant has unique nutritional requirements that are obtained through the roots from the soil. Nutrients are stored in soil on “exchange sites” of the organic and clay components. Calcium, magnesium, ammonium, potassium and the vast majority of the micronutrients are present as cations under most soil pHs.

4.1.2  Composition of Soils

Soils comprise a mixture of inorganic and organic components: minerals, air, water, and plant and animal material. Mineral and organic particles generally compose roughly 50 percent of a soil’s volume. The other 50 percent consists of pores—open areas of various shapes and sizes. Networks of pores hold water within the soil and also provide a means of water transport. Oxygen and other gases move through pore spaces in soil. Pores also serve as passageways for small animals and provide room for the growth of plant roots.

A)  Inorganic Material

The mineral component of soil is made up of an arrangement of particles that are less than 2.0 mm in diameter. Soil scientists divide soil particles, into three main size groups: sand, silt, and clay. According to the classification scheme used by the United States Department of Agriculture (USDA), the size designations are: sand, 0.05 to 2.00 mm; silt 0.002 to 0.05 mm; and clay, less than 0.002 mm. Depending upon the parent rock materials from which they were derived, these assorted mineral particles ultimately release the chemicals on which plants depend for survival, such as potassium, calcium, magnesium, phosphorus, sulfur, iron, and manganese.
B) Organic Material

Organic materials constitute another essential component of soils. Some of this material comes from the residue of plants—for example, the remains of plant roots deep within the soil, or materials that fall on the ground, such as leaves on a forest floor. These materials become part of a cycle of decomposition and decay, a cycle that provides important nutrients to the soil. In general, soil fertility depends on a high content of organic materials.

C) Water

Soils are also characterized according to how effectively they retain and transport water. Once water enters the soil from rain or irrigation, gravity comes into play, causing water to trickle downward. Soils differ in their capacity to retain moisture against the pull exerted by gravity and by plant roots. Coarse soils, such as those consisting of mostly sand, tend to hold less water than do soils with finer textures, such as those with a greater proportion of clays.

Water also moves through soil pores by capillary action. This is the kind of movement in which water molecules move because they are more attracted to the pore walls than to one another. Such movement tends to occur from wetter to drier areas of the soil. The attraction of water molecules to each other is an example of cohesion. The attraction of water molecules to other materials, such as soil or plant roots, is a type of adhesion.
4.1.3 Soil Formation

Soil formation is the process by which rocks are broken down into progressively smaller particles and mixed with decaying organic material.

Bedrock begins to disintegrate as it is subjected to freezing-thawing cycles, rain, and other environmental forces (I). The rock breaks down into parent material, which in turn breaks into smaller mineral particles (II). The organisms in an area contribute to soil formation by facilitating the disintegration process as they live and adding organic matter to the system when they die. As soil continues to develop, layers called horizons form (III).

![Image of soil profile showing soil horizons]

**Fig. 4.1 Soil profile showing soil horizons**

The A horizon, the horizon at the top, is usually richer in organic matter, while the lowest layer, the C horizon, contains more minerals and still looks much like the parent material. The soil will eventually reach a point where it can support a thick cover of vegetation and cycle its resources effectively (IV). At this stage, the soil may feature a B horizon, where leached minerals collect.

Soil formation is an ongoing process that proceeds through the combined effects of five soil-forming factors: parent material, climate, living organisms, topography, and time. Each combination of the five factors produces a unique type of soil that can be identified by its characteristic layers, called horizons. Soil formation is also known as pedogenesis (from the Greek words pedon, for “ground,” and genesis, meaning “birth” or “origin”).
A) Parent Material

The first step in pedogenesis is the formation of parent material from which the soil itself forms. Roughly 99 percent of the world’s soils derive from mineral-based parent materials that are the result of weathering, the physical disintegration and chemical decomposition of exposed bedrock. Bedrock itself does not directly give rise to soil. Rather, the gradual weathering of bedrock, through physical and chemical processes, produces a layer of rock debris called regolith. Further weathering of this debris, leading to increasingly smaller and finer particles, ultimately results in the creation of soil.

B) Climate

Climate directly affects soil formation. Water, ice, wind, heat, and cold cause physical weathering by loosening and breaking up rocks. Water in rock crevices expands when it freezes, causing the rocks to crack. Rocks are worn down by water and wind and ground to bits by the slow movement of glaciers. Climate also determines the speed at which parent materials undergo chemical weathering, a process in which existing minerals are broken down into new mineral components. Chemical weathering is fastest in hot, moist climates and slowest in cold, dry climates.

C) Living Organisms

As the parent material accumulates, living things gradually gain a foothold in it. The arrival of living organisms marks the beginning of the formation of true soil. Mosses, lichens, and lower plant forms appear first. As they die, their remains add to the developing soil until a thin layer of humus is built up. Animals’ waste materials add nutrients that are used by plants. Higher forms of plants are eventually able to establish themselves as more and more humus accumulates. The presence of humus in the upper layers of a soil is important because humus contains large amounts of the elements needed by plants.

D) Topography

Topography, or relief, is another important factor in soil formation. The degree of slope on which a soil forms helps to determine how much rainfall will run off the surface and how much will be retained by the soil.

E) Horizons

Most soils, as they develop, become arranged in a series of layers, known as horizons. These horizons, starting at the soil surface and proceeding deeper into the ground, reflect different properties and different degrees of weathering.
Soil scientists have designated several main types of horizons. The surface horizon is usually referred to as the O layer; it consists of loose organic matter such as fallen leaves and other biomass. Below that is the A horizon, containing a mixture of inorganic mineral materials and organic matter. Next is the E horizon, a layer from which clay, iron, and aluminum oxides have been lost by a process known as leaching. Removal of materials in this manner is known as eluviation, the process that gives the E horizon its name. Below E horizon is the B horizon, in which most of the iron, clays, and other leached materials have accumulated. The influx of such materials is called illuviation. Under that layer is the C horizon, consisting of partially weather bedrock, and last, the R horizon of hard bedrock.

This arrangement of layers atop one another is known as soil profile. Soil profiles change constantly but usually very slowly. Under normal conditions, soil at the surface is slowly eroded but is constantly replaced by new soil that is created from the parent material in the C horizon.

### 4.1.4 Soil Characteristics

Scientists can learn a lot about a soil’s composition and origin by examining various features of the soil. Color, texture, aggregation, porosity, ion content, and pH are all important soil characteristics.

**A) Color**

Soils possess a wide range of colors. In the surface soil horizons, a dark color usually indicates the presence of organic matter. Soils with significant organic material content appear dark brown or black. The most common soil hues are in the red-to-yellow range, getting their color from iron oxide minerals coating soil particles. Red iron oxides dominate highly weathered soils. Soils frequently saturated by water appear gray, blue, or green because the minerals that give them the red and yellow colors have been leached away.

**B) Texture**

A soil’s texture depends on its content of the three main mineral components of the soil: sand, silt, and clay. Texture is the relative percentage of each particle size in a soil. Soils with predominately large particles tend to drain quickly and have lower fertility. Very fine-textured soils may be poorly drained, tend to become waterlogged, and are therefore not well-suited for agriculture. Soils with a medium texture and a relatively even proportion of all particle sizes are most versatile. A combination of 10 to 20 percent clay, along with sand and silt in roughly equal amounts, and a good quantity of organic materials, is considered an ideal mixture for productive soil.

**C) Aggregation**

Individual soil particles tend to be bound together into larger units referred to as aggregates or soil peds. Aggregation occurs as a result of complex chemical forces...
acting on small soil components or when organisms and organic matter in soil act as glue binding particles together. Soil peds range in size from very fine—less than 1 mm—to very coarse—greater than 10 mm.

D) Porosity
The part of the soil that is not solid is made up of pores of various sizes and shapes—sometimes small and separate, sometimes consisting of continuous tubes. The size, number, and arrangement of soil pores is known as the soil’s porosity. Porosity greatly affects water movement and gas exchange. Well-aggregated soils have numerous pores, which are important for organisms that live in the soil and require water and oxygen to survive. The transport of nutrients and contaminants will also be affected by soil structure and porosity.

E) Ion Content
Soils also have key chemical characteristics. The surfaces of certain soil particles, particularly the clays, hold groupings of atoms known as ions. These ions carry a negative charge. Like magnets, these negative ions (called anions) attract positive ions (called cations). Cations, including those from calcium, magnesium, and potassium, then become attached to the soil particles, in a process known as cation exchange. The chemical reactions in cation exchange make it possible for calcium and the other elements to be changed into water-soluble forms that plants can use for food. Therefore, a soil’s cation exchange capacity is an important measure of its fertility.

F) pH
Another important chemical measure is soil pH, which refers to the soil’s acidity or alkalinity. The pH of a soil will often determine whether certain plants can be grown successfully.

4.1.5 Soil Erosion

For most of human history, soil has not been treated as the valuable and essentially nonrenewable resource that it is. Erosion has devastated soils worldwide as a result of overuse and misuse. In recent years, however, farmers and agricultural experts have become increasingly concerned with soil management.

A) Erosion
Erosion is the wearing away of material on the surface of the land by wind, water, or gravity. In nature, erosion occurs very slowly, as natural weathering and geologic processes remove rock, parent material, or soil from the land surface. Human activity, on the other hand, greatly increases the rate of erosion.
In a cultivated field from which crops have been harvested, the soil is often left bare, without protection from the elements, particularly water. Raindrops smash into the soil, dislodging soil particles. Water then carries these particles away. This movement may take the form of broad overland flows known as sheet erosion. More often, the eroding soil is concentrated into small channels, or rills, producing so-called rill erosion. Gravity intensifies water erosion.

Wind erosion occurs where soils are dry, bare, and exposed to winds. Very small soil particles can be suspended in the air and carried away with the wind. Larger particles bounce along the ground in a process called saltation.

### 4.2 Soil Pollution

Unhealthy soil management methods have seriously degraded soil quality, caused soil pollution, and enhanced erosion. In addition to other human practices, the use of chemical fertilizers, pesticides, and fungicides has disrupted the natural processes occurring within the soil resulting in soil pollution. **Soil pollution** is a buildup of toxic chemical compounds, salts, pathogens, or radioactive materials that can affect plant and animal life. The concern over soil contamination stems primarily from health risks, both of direct contact and from secondary contamination of water supplies.

All kinds of soil pollutants originate from a source. The source is particularly important because it is generally the logical place to eliminate pollution. After a pollutant is released from a source, it may act upon a receptor. The receptor is anything that is affected by the pollutant. The following sub-unit describes some of the most common sources of soil pollution.

#### 4.2.1 Sources of Soil Pollution

The most common toxic soil pollutants include metals and their compounds, organic chemicals, oils and tars, pesticides, explosive and toxic gases, radioactive materials, biologically active materials, combustible materials, asbestos and other hazardous materials. These substances commonly arise from the rupture of underground storage tanks; application of chemical fertilizers, pesticides, and fungicides; percolation of contaminated surface water to subsurface strata; leaching of wastes from landfills or direct discharge of industrial wastes to the soil etc.

#### 4.2.1.1 Pollution by Heavy metals

Heavy metal soil contaminants such as cadmium, lead, chromium, copper, zinc, mercury and arsenic, are a matter of great concern. Naturally all soils contain heavy metals. However, their levels are increased by:
- industry (non-ferrous industries, power plants, iron, steel and chemical industries);
- agriculture (irrigation with polluted water, use of mineral fertilizers)
- waste incineration;
- combustion of fossil fuels; and
- road traffic.

### 4.2.1.2 Pollution by Pesticides and organic contaminants

Pesticides that are used in agricultural practices pollute the soil directly by affecting the organisms that reside in it. Organic pollutants enter the soil via atmospheric deposition, direct spreading onto land, contamination by wastewater and waste disposal.

Organic contaminants include pesticides and many other components, such as oils, tars, chlorinated hydrocarbons, PCBs and dioxins.

The use of pesticides may lead to:
- destruction of the soil’s micro-flora and fauna, leading to both physical and chemical deterioration;
- severe yield reduction in crops; and
- leaching of toxic chemicals into groundwater and potentially threatening drinking water resources.

### 4.2.2. Effects of Soil Pollution

Existence of the ecosystems requires existence of plants. Humans and animals cannot survive without plants. Soil is not only a source of nutrition but also a place for plants to stand. Pollution of agricultural soils by heavy metals is known to reduce agricultural yield and increase levels of these toxic heavy metals in agricultural products, and thus to their introduction into the food chain. Vegetables and crop plants grown in such soils take up these toxic elements and pose health risk to humans and animals feeding on these plants.

The major concern about soil pollution is that there are many sensitive land uses where people are in direct contact with soils such as residences, parks, schools and playgrounds. Other contact mechanisms include contamination of drinking water or inhalation of soil contaminants which have vaporized. There is a very large set of health consequences from exposure to soil contamination depending on pollutant type, pathway of attack and vulnerability of the exposed population.
Organic pollutants which are directly applied into soils or deposited from the atmosphere may be taken up by plants or leached into water bodies. Ultimately they affect human and animal health when taken up through the food they eat and the water they drink. More recently research has revealed that many chemical pollutants, such as DDT and PCBs, mimic sex hormones and interfere with the human body’s reproductive and developmental functions. These substances are known as endocrine disrupters. Another interesting example is the contamination of milk that occurred in Hawaii in early 1982. It was found that milk from several sources on Oahu contained very high levels of heptachlor. This is a pesticide that causes cancer and liver disorders in mice and is suspected to be human carcinogen. The source of the heptachlor was traced to be chopped-up pineapple leaves fed to cattle.

Soils might be affected less by pollution compared to water or air. However, cleaning polluted soils is more difficult, complex and expensive than water and air. Soil reclamation is a too costly activity.

In addition to its effects on the economy, health, and natural resources, pollution has social implications. Research has shown that low-income populations do not receive the same protection from environmental contamination as do higher-income communities. Toxic waste incinerators, chemical plants, and solid waste dumps are often located in low-income communities because of a lack of organized, informed community involvement in municipal decision-making processes.

### 4.2.3 Control of Soil Pollution

Soil pollution prevention requires proper land use planning and provision of environmental infrastructures. For example, industries that can cause accidental discharge of pollutants and toxic chemicals will not be allowed to be sited within water catchments.
Once preventive measures are established, controls are stringently enforced to ensure that pollution control equipment are properly maintained and operated, and effluents discharged meet emission standard. The quality of the environment is monitored regularly to ensure that these pollution control measures are adequate.

Biological way controlling pests and diseases in agriculture that relies on natural predation rather than chemicals is another method of controlling soil pollution.

Most important in preventing soil or other pollutions is educating the people. Anti-litter campaigns for example, can educate people against littering.

### 4.3 Formative Assessment

1. The soil component which is comes from the weathering of rocks constitutes
   a) the inorganic component of the soil
   b) the organic component of the soil
   c) not necessary for plant growth
   d) none

2. Which of the following does not contribute to the chemical composition of soils?
   a) the chemical nature of underlying rocks
   b) volcanic activity
   c) rainfall
   d) none

3. Constituents of soils which are easily leached by rain and taken up by plants are stored
   a) in all parts of the soil
   b) on the exchange sites of the organic and clay components
   c) in the silicate fraction of the soil
   d) only in the organic fraction of the soil

4. The particle size of which of the following the smallest?
   a) sand   b) silt   c) clay   d) gravel
5. Soils containing a greater proportion of which of the following tends to drain quickly than the others?
   a) sand  b) silt  c) clay  d) gravel

6. Living organisms in the soil
   a) contribute to the organic component of the soil
   b) do have no role in soil formation
   c) facilitate the disintegration process of rocks in soil formation
   d) a & c

7. The soil horizon which is rich in minerals is
   a) A horizon,  b) B horizon  c) C horizon  d) the O layer

8. What is the first step in pedogenesis?
   a) disintegration of parent materials
   b) formation of the parent material
   c) decay of plant materials
   d) formation of the soil horizons

9. Regolith is
   a) bedrock
   b) soil formed by the weathering of rocks
   c) a layer of rock debris formed by the gradual weathering of bedrock
   d) the organic soil component

10. The layer of soil from which the eluviation of clay, iron, and aluminum oxides-takes place by leaching is
    a) A horizon  b) B horizon  c) C horizon  d) E horizon

11. Unhealthy soil management methods
    a) degrades soil quality  c) enhances erosion.
    b) causes soil pollution  d) all
12. Most common toxic soil pollutants may arise from
   a) leaching of wastes from landfills
   b) Application of animal dung to the soil
   c) acid rain
   d) decaying plants

13. Which of the following human activities does not increase the level of heavy metals in soils?
   a) Industrial and agricultural activities
   b) Waste incineration
   c) Combustion of fossil fuels
   d) None

14. Organic pollutants enter the soil through
   a) bedrock weathering
   b) decomposition of plant and animal debris
   c) atmospheric deposition
   d) all

15. Pollution of agricultural soils by heavy metals can
   a) increase agricultural yield by providing plants sufficient amount of essential metals
   b) introduce toxic heavy metals into the food chain
   c) increase the number of soil microorganisms which can boost agricultural yield
   d) all
4.4 Answers to Formative Assessment

1. a) the inorganic component of the soil
2. d) none
3. b) on the exchange sites of the organic and clay components
4. c) clay
5. a) sand
6. d) a & c
7. c) C horizon
8. b) formation of the parent material
9. c) a layer of rock debris formed by the gradual weathering of bedrock
10. d) E horizon
11. d) all
12. a) leaching of wastes from landfills
13. d) None
14. c) atmospheric deposition
15. b) introduce toxic heavy metals into the food chain
XI. Glossary

Environment: All the external factors that affect an organism.

Atmosphere: The mixture of gases surrounding any celestial object that has a gravitational field strong enough to prevent the gases from escaping; especially the gaseous envelope of Earth.

Ecosystem: Organisms living in a particular environment, and the physical parts of the environment that affect them.

Geosphere: The solid earth, including soil, which supports most plant life.

Hydrosphere: Earth’s water.

Biosphere: All living things on Earth.

Anthroposphere: That part of the environment made or modified by humans and used for their activities.

Fauna and Flora: Animals and Plants collectively.

Ozone layer: A thin layer in the upper atmosphere that is rich in O₃ molecules and serves to shield Earth from the Sun’s harmful ultraviolet rays.

Fossil fuel: The organic matter of wood, or the hydrocarbons of natural gas, coal, petroleum etc. that have been formed from the partially decayed animals and vegetable matter of living things that inhabited the Earth in eras long past.

Pollution: The presence of an excess of a substance generated by human activity in the wrong environmental location.

Acid rain: Rain having abnormally high acidity as a result of interactions with atmospheric pollutants.

Photochemical smog: Air pollution produced when sunlight causes hydrocarbons and nitrogen oxides from automotive exhaust to combine.

Greenhouse Effect: The warming of the Earth by solar heat trapped through the insulating effect of atmospheric gases.

Global Warming: Increase in the average temperature of the atmosphere.

Water Pollution: Water Pollution, contamination of streams, lakes, underground water, bays, or oceans by substances harmful to living things.

Air Pollution: Addition of harmful substances to the atmosphere resulting in damage to the environment, human health, and quality of life.

Hazardous Wastes: Solid, liquid, or gaseous wastes that can cause death, illness, or injury to people or destruction of the environment if improperly treated, stored, transported, or discarded.

Soil horizons: Development of soil in a series of layers.

Climate: The prevailing weather condition in a particular region.
XII. Compiled List of Compulsory Readings

Reading #1

**Air Pollution and chemical Reactions in the Atmosphere** in ‘Comp-R-airpollut-ants’ in accompanying CD.

**Abstract:** This reading provides a discussion on the major air pollution problem. This has typically been high levels of smoke and sulfur dioxide arising from the combustion of fossil fuels that contain sulfur. The major threat to air pollution is now posed by traffic emissions. In all except worst-case situations, industrial and domestic pollutant sources, together with their impact on air quality, tend to be steady-state or improving over time. However, traffic pollution problems are worsening world-wide. The principal pollutants produced by industrial, domestic and traffic sources such as: sulfur dioxide, nitrogen oxides, carbon monoxide, fine particles, ozone, toxic organic micro-pollutants, volatile organic compounds etc are provided in the reading.

**Rationale:** This reading is written to provide you a fairly detailed discussion on the principal air pollutants in the environment and the various reactions these pollutants undergo. The reading also provides the definition of acid-rain and elaborates how it results. It discusses the reason why all rain water, even the rain water pouring in an unpolluted atmosphere is acidic.

The temperature, pressure, chemical composition variation in the various layers of atmosphere is discussed in detail.

Reading #2

**Nature and Types of Water Pollutants;** ‘Comp-R-waterpollutants-andWHO guideline’ in accompanying CD.

**Abstract:** This reading provides a description of the major water pollutants. Based on their nature the major water pollutants are classified as chemical, biological, or physical materials that degrade water quality. Based on the set of hazards they present they are also classed into eight categories: Petroleum Products, Pesticides and Herbicides, Heavy Metals, Hazardous Wastes, Excess Organic Matter, Sediment, Infectious organisms, and thermal Pollution. A brief discussion on each pollutant is provided in the reading.

Water, released by residences, businesses and industries in a community after being used for various purposes is said to be waste water. This includes the water we use to wash our clothes, ourselves, our dishes, our food as well as the water we flush down the toilet. Untreated waste-water is a potential pollutant to surface and ground water and has to be treated before release.
Waste water treatment may be divided into three major categories:

- Purification for domestic use
- Treatment for specialized industrial applications
- Treatment of wastewater to make it acceptable for release or reuse

**Rationale:** This reading provides you the definition for water pollution and the parameters used to describe the purity of water. Brief descriptions on waste-water and its sources, the method used to treat waste-water before releasing it to its origin are also provided.

A student of Environmental Chemistry should understand that drinking water should contain a relatively high amount of some elements (minerals) while the level of toxic heavy metals should be low. The limits of each of these substances in drinking water as provided by the WHO is given in this reading.

**Reading #3**

**Carbondioxide and Water Acidity.** pdf file ‘Comp-R-Water-acidity’ in the accompanying CD.

**Abstract:** Surface water, ground water or water existing in any medium is either acidic, neutral or alkaline. The simplest definition of acidity, pH, is provided in this reading. In this case, “acidity” is related to proton concentration and pH is defined as the negative logarithm to the base 10 of the hydronium concentration of a solution.

Dissolved carbon dioxide is known to be the most common source of acidity in water. It enters the water through equilibrium with the atmosphere. A detailed treatment of this equilibrium is given in the reading.

The pH of a water body that does not contain lime will be different from that of a water containing lime. The pHs of both kinds of water can be calculated by considering the various equilibrium existing in the water. The reading provides a brief discussion on the calculation of pH values of such water bodies by applying the Henry’s Law.

The capacity of a water body to neutralize H+ is defined as its alkalinity. It is similar to buffer capacity in that higher alkalinity is associated with a body of water’s ability to “soak up” proton without altering the pH and is different from basicity, which is directly related to the pH. The higher the pH, the more basic is the water.

**Rationale:** PH is one of the parameters used to describe the purity of water. Therefore, as an environmental chemistry student you need to describe the reasons behind the level of acidity of water bodies. This reading is absolutely essential in this regard since it provides brief but clear discussion on the main source of water acidity, the equilibrium existing in water bodies and which are responsible for water acidity and so on. The definition of alkalinity, which is an important concept in understanding the effects of acid rain, is also provided in sufficient depth for the level.
**Reading #4**

*Green Chemistry, Preventing pollution*, pdf file ‘GreenChem-Note’ in the accompanying CD

**Abstract:** Pollution prevention is undoubtedly better than seeking for remedial actions after pollution. Green chemistry is a chemical philosophy encouraging the design of products and processes that reduce or eliminate the use and generation of hazardous substances. Simply stated it is the use of chemistry techniques and methodologies that reduce or eliminate the use or generation of feedstocks, products, by-products, solvents, reagents, etc., that are hazardous to human health or the environment and maximize the efficiency of any chemical choice.

The main goal of Green Chemistry is to reduce and prevent pollution at its source. It is both the chemistry of the future and the chemistry of today.

**Rationale:** As a chemistry student you may be required to describe the noble way of stopping pollution at its source. This reading provides you some environmentally friendly ways of synthesizing some substances vis-à-vis other methods which are environmentally non-friendly. The reading gives you an insight on the endeavours of chemists to stopping environmental pollution at its source than trying to look for a remedial method after polluting it.
XIII. Compiled List of Useful Links

Useful Link #1

IB Chemistry Environmental Chemistry – Wikibooks, collection of open-content textbooks
Title: IB Environmental Chemistry Notes I. Primary Air Pollution
URL: http://en.wikibooks.org/wiki/IB_Chemistry_Environmental_Chemistry
Description: This site provides relevant information on atmospheric pollution. Moreover, students and other visitors interested in the topic of environmental chemistry IB Chemistry Environmental Chemistry to be a valuable web resource for finding the information or answers they are seeking, and are encouraged to take advantage of the site.
Rationale: Students are advised to visit this link because it provides relevant readings which are useful in strengthening their understanding of the topics on atmospheric chemistry, specifically on atmospheric pollution.

Useful Link #2

Environmental chemistry - Wikipedia, the free encyclopedia
Title: Environmental Chemistry
URL: http://en.wikipedia.org/wiki/Environmental_chemistry
Description: Definitions and detailed descriptions of most of the terms mentioned in this module are provided in this site. The site also provides the differences between environmental chemistry and green chemistry which are confused by many students of chemistry.
Rationale: Environmental chemistry involves first understanding how the uncontaminated environment works, which chemicals in what concentrations are present naturally, and with what effects. Without this it would be impossible to accurately study the effects humans have on the environment through the release of chemicals.
Students are advised to visit this link because it provides useful readings on contamination and by relating with natural concentrations of contaminants. It also describes anthropogenic impacts on the environment.
### Useful Link #3

**Environmental chemistry.Com**

**Title:** Environmental Chemistry & Hazardous Materials, News, Careers & Resources

**URL:** http://environmentalchemistry.com/

Screen capture

<table>
<thead>
<tr>
<th>Environmental Chemistry &amp; Hazardous Materials News, Careers &amp; Resources</th>
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<tr>
<td><strong>Site Menu</strong></td>
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<td>Skip menu and go to content</td>
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<tr>
<td><strong>Environmental Issues, Consumer Health &amp; Food Safety Concerns Chemistry</strong></td>
</tr>
<tr>
<td><strong>Description:</strong> This site provides brief but important descriptions on all the topics covered in this module. This site also offers links to related websites.</td>
</tr>
<tr>
<td><strong>Rationale:</strong> Students are advised to visit this site to get detailed descriptions of all the topics which are not discussed in depth in the module. The topics covered in the site and which are relevant to the discussions in this module are: stratospheric chemistry (the ozone layer); air pollution; chemistry of the atmosphere; the greenhouse effect and global warming.</td>
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Useful Link #4

Environmental Chemistry: Third Edition

Title: Environmental Chemistry

URL: http://bcs.whfreeman.com/envchem3e/default.asp?s=&n=&i=&v=&o=&ns=0&uid=0&ra

Description: This website is a book companion site for ‘Environmental chemistry’, third edition (published by W H Freeman). This site has been developed to serve as an additional free resource for students and instructors using the textbook.

Rationale: This is a useful website to students in that, it offers exercises and links to related websites. The topics: stratospheric chemistry (the ozone layer); ground-level air pollution; detailed chemistry of the atmosphere; the greenhouse effect and global warming; climate change in the future (predictions, consequences and controls); alternative fuels and the hydrogen economy; the chemistry of natural waters; the pollution and purification of water; toxic heavy metals; hazardous and municipal wastes, and the contamination of soils and sediments are well discussed.

Useful Link #5

Virtual ChemBook

Title: Environmental chemistry

URL: http://www.elmhurst.edu/~chm/vchembook/

Screen capture

Description: This site extensively covers all topics of introductory environmental chemistry course. The site provides suggestion on the order of viewing the site but student can select any topic that they wish to learn about.

Rationale: The site provides excellent reading materials which will help the student to study all the topics covered in this module. In addition to relevant reading materials, explorer and master quizzes which will help the student to make self assessment are given.
Useful Link #6

General Chemistry Glossary: Environmental Chemistry

Title: Environmental Chemistry

URL: http://antoine.frostburg.edu/chem/senese/101/environmental/glossary.shtml

Description: This page provides a general glossary of terms for environmental chemistry, with brief definitions and hyperlinks to related terms.

Rationale: This webpage provides brief definitions of nearly all of the terms mentioned in this module. Students will find the page useful when they are looking for brief definitions of the terms which might not be defined in that form in the module. The webpage also provides useful links for environmental chemistry.

Useful Link #7

Science, Engineering and Technology

Title: Environmental Chemistry

URL: http://www.intute.ac.uk/ sciences/cgi-bin/search.pl?term1=environmental+chemistry&limit=0

Screen capture

Description: This webpage provides discussions on the whole range of topics including: aquatic chemistry, water pollution, atmospheric chemistry and pollution, greenhouse effect, and green chemistry.

Rationale: The reading materials provided in this website are very important and relevant to study the subject matter covered in the outline of this module. Students can access clearly presented materials which discuss core concepts in aquatic chemistry, atmospheric chemistry, greenhouse effect and global warming, and ozone depletion. The contents of the material are well organized and could be accessed easily.
Useful Link #8

Green Pack

Title: Green Pack: Environmental Components
URL: http://greenpack.rec.org/soil/index.shtml

Description: This site provides a collection of instructional materials for environmental education. It has extremely important topics in the environmental component subsection that are relevant to the learning activities provided in this module.

Rationale: Under Environmental components we have: Air, water, soil and biodiversity. The discussions provided in all these topics are extremely relevant to the learning activities in this module. Students are advised to visit this link to strengthen their understanding in any of the topics: atmospheric chemistry, aquatic chemistry, soil and pollution.
XIV. Synthesis of the Module

This module is designed to equip the students with general concepts in environmental chemistry. It aims to apply knowledge of chemistry to understand environmental issues. The entire module comprises four learning activities.

Before dealing with the detailed chemistry of the three major components of our environment, students should be able to define and discuss the various parts of the environment, appreciate the profound uses of our natural resources and the way these natural resources are threatened by reckless human activities. Therefore, the first learning activity provides a general discussion on the environment. The threats of natural resources consumption by human beings, population increase, industrialization and pollution are discussed in this unit.

Learning activity 2 is a discussion on the atmosphere and its pollution. In this unit, classification of the atmosphere based on temperature variation with altitude, composition of the different regions of the atmosphere and the chemical reactions taking place in the atmosphere are discussed in detail. In addition, the most pressing issue of the 21st century, atmospheric pollution, is given due emphasis in this unit. The major classes of air pollutants and their sources, the ozone layer depletion, acid rain and global warming issues which result from air pollution are discussed sufficiently.

The 3rd learning activity is on the hydrosphere and water pollution. The properties of water which make it unique relative to other substances, the chemical reactions that take place in water bodies, the factors that influence the acidic properties of natural water bodies, and water pollution are the main focuses of discussion in this learning activity.

The 4th learning activity is on soil chemistry and soil pollution. The process in the formation of soils, the major components of soils and their classification, soil erosion and its impacts, soil pollution and the sources of soil pollution, effects of soil pollution are discussed in this unit.
XV. Summative Evaluation

1) Which of the following is false about the atmosphere?
   a) it enables us to have ambient temperature by absorbing part of the radiation reaching the earth.
   b) protects life on earth from harmful radiations of outer space.
   c) is the source of carbondioxide for plant photosynthesis and of oxygen for respiration.
   d) none

2) The geosphere is divided into different layers. Which of this layers is most important for environmental sciences?
   a) The lithosphere
   b) The crust and upper mantle
   c) The inner core
   d) a & b

3) The production of high-energy biomass by plant photosynthesis is represented by which of the following reactions?
   a) $\text{CO}_2 + \text{H}_2\text{O} \xrightarrow{hv} \{\text{CH}_2\text{O}\} + \text{O}_2(g)$
   b) $\{\text{CH}_2\text{O}\} + \text{O}_2(g) \rightarrow \text{CO}_2 + \text{H}_2\text{O}$
   c) $2\{\text{CH}_2\text{O}\} \rightarrow \text{CO}_2(g) + \text{CH}_4(g)$
   d) done

4) Excessive use of fossil fuel results in,
   a) an increase in global $\text{CO}_2$ level.
   b) a decrease in global temperature.
   c) a decrease in sea levels
   d) an increase in ice level of the icecaps.

5) The largest gaseous component of the earth’s atmosphere is
   a) Oxygen   b) Carbondioxide   c) Nitrogen   d) Sulfurdioxide
6) Atmospheric pressure
   a) increases with an increase in altitude
   b) decreases with an increase in altitude
   c) does not show difference with altitude
   d) increases with altitude in the stratosphere.

7) With increasing altitude in the troposphere,
   a) both temperature and pressure increase.
   b) temperature decreases while pressure is increasing.
   c) both temperature and pressure decrease.
   d) temperature increases while pressure is decreasing.

8) With an increase in altitude, atmospheric temperature
   a) increases in the stratosphere and then goes on decreasing in the mesosphere.
   b) increases in the troposphere and then decreases in the stratosphere.
   c) increases in the mesosphere and then decreases in the thermosphere.
   d) increases in the troposphere, mesosphere and thermosphere.

9) Atmospheric temperature reaches its minimum value at the end of
   a) the stratosphere.
   b) the mesosphere.
   c) the troposphere
   d) the thermosphere

10) Isothermal layer is
    a) the atmospheric layer above the thermosphere.
    b) layer of the atmosphere where temperature increases steadily.
    c) layer of the atmosphere where temperature decreases steadily.
    d) layer of the atmosphere where temperature remains constant.

11) In the thermosphere, while temperature seems extreme, the amount of heat energy
    involved is very small. Which of the following is the reason for this fact?
    a) Heat stored by the molecules is lost as a result of high speed and frequent
       collision between molecules in the thermosphere.
    b) There are no large number of molecules which can store heat.
    c) The gaseous molecules found in the thermosphere are not good in storing heat
       as the molecules found in other parts of the atmosphere.
    d) All
12) Which of the following reactions show the removal of the hydroxyl ion from the troposphere?
   a)  \( H + O_2 \rightarrow HOO^- \)
   b)  \( CH_4 + HO^- \rightarrow H_3C^- + H_2O \)
   c)  \( H + HO^- \rightarrow H_2O \)
   d)  \( HO^- + HOO^- \rightarrow H_2O + O_2 \)

13) Ammonia is an important base in the air because
   a)  there are no other bases in the air to neutralize atmospheric acids except ammonia.
   b)  it is a weak base
   c)  it is water soluble and is able to neutralize atmospheric acids.
   d)  it is the only base that can neutralize acids found in the environment

14) Acid rain is a result of
   a)  the dissolution of oxygen released from plants in atmospheric moisture.
   b)  the dissolution of pollutant gases, such as sulfur dioxide from industrial emissions in rain or atmospheric moisture.
   c)  the dissolution ammonia from industrial emissions in rain or atmospheric moisture.
   d)  all

15) Rain water collected from an unpolluted atmosphere will be
   a) acidic  b) alkaline  c) neutral  d) none

16) Why are CFCs considered to be dangerous destructors of \( O_3 \)?
   a)  CFC molecules are stable, and are able to reach the stratosphere without being destroyed.
   b)  A single chlorine atom of CFC can take part in several chemical reactions that destroy \( O_3 \).
   c)  CFCs are the only chemical destroyers of \( O_3 \).
   d)  a & b
17) Which of the following is a result of global warming?
   a) An increase in the ice level of the ice caps.
   b) An increase in animal species
   c) An increase in crop productivity.
   d) Flooding of coastal cities.

18) Which of the following practices can reduce acid rain and other forms of air pollution?
   a) The use of alternative energy sources,
   b) Removal of pollutants from the products of combustion,
   c) Improving the efficiency of the combustion process. and
   d) All

19) Natural gas is recommended as an alternative energy source for motor vehicles because,
   a) Contains few sulfur impurities
   b) The world has a huge reserve
   c) It is a suitable energy source specially for motor vehicles
   d) a & b

20) Most of water’s unique properties are due to
   a) Its molecular weight
   b) Its dipole moment and ability to form hydrogen bonds
   c) Its molecular structure
   d) None

21) Water at 0°C is less dense than it is at 4°C. Which of the following is an advantage of this unique property of water?
   a) Protect coastal cities from flooding.
   b) Have more ice in the polar ice caps.
   c) Have cold water which is suitable for drinking
   d) Protecting aquatic animals from freezing in winter
22) Once water enters the soil from rain it trickles downward by
   a) irrigation
   b) the action of gravity
   c) capillary action
   d) b and c

23) The attraction of water molecules to each other is an example of
   a) cohesion.
   b) adhesion
   c) ionic bond
   d) coordinate covalent bonding

24) If the amount of dissolved salts in water is high
   a) water uptake by plant roots and seeds will increase.
   b) water uptake by plant roots and seeds will be reduced.
   c) the soil will not retain water
   d) b and c

25) Which of the unique properties of water serves distributing heat from one part
     of the globe to another?
   a) Its low density when frozen
   b) The high difference between its melting and boiling point temperatures.
   c) Its high specific heat capacity
   d) Its ability to dissolve many substances

26) What is the major negative impact of the growth of plants and algae in water
     bodies
   a) They consume the inorganic nutrient in the water
   b) They hinder other aquatic life from sun light
   c) Their decomposition consumes dissolved oxygen which is essential for aquatic
      animals
   d) Their decomposition consumes dissolved carbondioxide which is essential
      for aquatic animals
27) Thermal pollution can kill aquatic animals
   a) by decreasing the dissolved oxygen level
   b) by decreasing the quantity of water in water bodies by evaporation
   c) by increasing the level of dissolved gases in the water
   d) all

28) Which of the following reactions show the acidic nature of the bicarbonate ion in water?
   a) \( \text{HCO}_3^- \rightleftharpoons \text{CO}_3^{2-} + \text{H}^+ \)
   b) \( \text{HCO}_3^- + \text{H}^+ \rightarrow \text{CO}_2^{(aq)} + \text{H}_2\text{O} \)
   c) \( \text{CO}_2^{(aq)} + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{H}^+ \)
   d) all

29) The pH of a river was determined to be 8 and its \( \text{CO}_3^{2-} \) concentration was 2.5 \( x \) \( 10^{-5} \) M. Given the dissociation constant of bicarbonate ion to be 4.7 \( x \) \( 10^{-11} \), what will be the alkalinity of the river?
   a) 5.37 \( x \) \( 10^{-25} \)
   b) 5.32 \( x \) \( 10^{-5} \)
   c) 5.37 \( x \) \( 10^{-3} \)
   d) 5.32 \( x \) \( 10^{-3} \)

30) Eutrophication is
   a) the dissolution of oxygen in water bodies to a level that supports aquatic life.
   b) the depletion of oxygen from water bodies to deadly levels.
   c) the depletion of carbon dioxide from water bodies.
   d) b & c
Answers

1) d) none
2) d) a & b
3) a) $\text{CO}_2 + \text{H}_2\text{O} \xrightarrow{hv} \{\text{CH}_2\text{O}\} + \text{O}_2(g)$
4) a) an increase in global CO$_2$ level.
5) c) Nitrogen
6) b) decreases with an increase in altitude
7) c) both temperature and pressure decrease.
8) a) increases in the stratosphere and then goes on decreasing in the mesosphere.
9) b) the mesosphere.
10) d) layer of the atmosphere where temperature remains constant.
11) b) There are no large number of molecules which can store heat.
12) b) $\text{CH}_4 + \text{HO}^- \rightarrow \text{H}_3\text{C}^- + \text{H}_2\text{O}$
13) c) it is water soluble and is able to neutralize atmospheric acids.
14) b) the dissolution of pollutant gases, such as sulfur dioxide from industrial emissions in rain or atmospheric moisture.
15) a) acidic
16) d) a & b
17) d) flooding of coastal cities.
18) d) All
19) a) contains few sulfur impurities
20) b) its dipole moment and ability to form hydrogen bonds
21) d) protecting aquatic animals from freezing in winter
22) d) b and c
23) a) cohesion
24) b) water uptake by plant roots and seeds will be reduced.
25) c) Its high specific heat capacity
26) c) Their decomposition consumes dissolved oxygen which is essential for aquatic animals
27) a) by decreasing the dissolved oxygen level
28) a) $\text{HCO}_3^- \rightleftharpoons \text{CO}_3^{2-} + \text{H}^+$

29) c) $5.37 \times 10^{-3}$

30) b) the depletion of oxygen from water bodies to deadly levels.
XVI. References


XVII. Main Author of the Module

Academic background

B.Sc in Chemistry; Asmara University, Asmara, Eriteria (1985)
M.Sc in Analytical Chemistry; Addis Ababa University, Ethiopia (1990)
PhD in Environmental Anal. Chem.; Karlfranzens University, Graz, Austria (2001)

Dr. Dejene has thought various chemistry and environmental Chemistry courses to undergraduate and graduate students at Jimma University in Ethiopia. He is currently Associate Professor of Chemistry.

He has served as department head for many years and currently he is serving as dean of the faculty of Education at Jimma University.

XVIII. Student Records

Name of the excel file: Student Grade Records

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<th>Score in test 2, on units III and IV (30%)</th>
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