Module 2: The Scientific Method and Matter

The Scientific Method

Steps of the Scientific Method

1. Performing Experiments
2. Making Observations
3. Proposing a Hypothesis (based upon the observations made)
4. Confirming the Hypothesis (by repeated experimentation)
5. Proposing a Scientific Law

Step 1: Performing Experiments

An experiment is a set of steps (procedures) that are performed under controlled conditions to propose or test a hypothesis.

Step 2: Making Observations

Observations (a key factor in scientific studies as well as in everyday life) can be classified as:

Qualitative – Not numbers (Ex. The flower is purple)
Quantitative – Numbers (quantity + unit, Ex. The liquid is 33°C)

Step 3: Proposing a Hypothesis

A hypothesis is a tentative explanation to account for the observations of an experiment. A hypothesis is valid provided that one's assumptions to explain the observations of an experiment can be tested.

Step 4: Confirming the Hypothesis

The validity of the hypothesis needs to be confirmed via repeated and controlled experiments. In order to accept a hypothesis, there must be no inconsistencies between the hypothesis and the experimental observations. In the even of any inconsistencies, steps 1 through 4 must be repeated.

Step 5: Proposing a Scientific Law

By repeatedly performing experiments and modifying the hypothesis to account for the observations from these experiments, one is able to propose a scientific law.

Numerical Values

Scientific Notation

A very convenient way of expressing very large or very small numbers and at the same time provides a method of increasing efficiency in scientific calculations.

Number is expressed as: $N \times 10^{n}$
N: only 1 nonzero digit → N**.** …
n: integer, +/- whole number

Ex. 598.46 → 5.9846×10^2

Significant Figures

The number of digits that carry meaning, including all certain digits and one uncertain digit. This does not apply to counted items such as exact numbers and defined conversion factors which have an infinite number of significant figures.

Rule 1: All nonzero digits are significant figures
Ex. 135.62 g (5 sig.fig.)

Rule 2: Excludes all leading zeros
Ex. 0.000356 L (3 sig.fig.)

Rule 3: Zeros between nonzero digits are counted
Ex. 1.056 g (4 sig.fig.)

Rule 4: Terminal zeros count after a decimal/decimals make zeros sig.figs
Ex. 2.3700 g (5 sig.fig.)
Ex. 200. cm (3 sig.fig.)

SI System of Units

Length: Meter (m)

Volume: Cubic meter (m^3)

$$1L = 1dm^3 = 10^{-3}m^3 = 10^3\ cm^3$$
$$1mL = 1\ cm^3 = 10^{-3}\ dm^3 = 10^{-3}\ L = 10^{-6}\ m^3$$

Mass: Kilogram (kg)

Density: Kilogram per cubic meter (kg/m^3)

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Area: Meter squared (m^2)

Common SI Prefixes

Prefix	Multiple	Symbol
Giga	10^{9}	G
Mega	10^{6}	M
Kilo	10^{3}	k
Centi	10^{-2}	c
Milli	10^{-3}	m
Micro	10^{-6}	μ*
Nano	10^{-9}	n

Other SI Conversions:

1.0 g = 10^3 mg
1.0 L = 10^6 μL

Examples:
Nanosecond = ns = 10^{-9} s
Micrometer = μm = 10^{-6} m

Chemical Calculations

Rules for Significant Figures

1. For addition/subtraction, the final answer has the same number of decimal places as the least precise measurement.
   Ex. 25.0 g + 22.41 g + 1.234 g = 48.6 g

2. For multiplication/division, the final answer has the same number of significant figures as the measurement with the least.
   Ex. 9.20 g x 2.450 = 22.5 g (3 sig.fig.)

3. Exact numbers, unit conversion factors and constants don't effect the number of significant figures in the final answer (only the measured quantity does).
   Ex. 2.35 g x 8 = 18.8 g
   Ex. 31.10 in as cm (1 in = 2.54 cm), 31.10 in x 2.54 = 78.99 cm

Rules for Rounding Off Digits

1. For multi-step calculations only round at the end to the correct number of significant figures.

2. Round >5 up one, <5 down one.

3. Round 5 up if preceding number is odd, down if it's even.
   Ex. 16.65 mL → 16.6 mL

Dimensional Analysis

In this method the identical units are multiplied or canceled using conversion factors to change the units that a measured quantity is expressed in.

Ex. 1.0 cm x 2.1 cm = 2.1 cm^2
Ex. 10.4 ~~g~~ / 2.0 ~~g~~ = 5.2

Step 1: Write the equation(s) relating the units
Step 2: State the relationship as a fraction (also called conversion factor)
Step 3: Multiply to cancel unwanted units and gives the final answer in the required unit

Example 1

How many Canadian dollars would you have to pay to buy a souvenir in Delhi costing 251.10 Indian Rupees?

Step 1: The equation relating the units is:

$1.00 = 31.00 Rupees

Step 2: The conversion factors are:

$$\frac{\$1.00}{31.00\ \text{Rupees}} \quad \text{and} \quad \frac{31.00\ \text{Rupees}}{\$1.00}$$

Step 3: Choose the conversion factor to get the answer in dollars:

$$251.10\ \cancel{\text{Rupees}} \times \frac{\$1.00}{31.00\ \cancel{\text{Rupees}}} = \$8.10$$

Example 2

What is the mass of an object in milligrams that weighs 10.31 lbs?

Step 1: The equations relating the units are:

1.0 lb = 453.6 g and 1.00g = 1.00×10^3 mg

Step 2: The conversion factors are:

$$\frac{1.00\ \text{lb}}{453.6\ \text{g}} \quad \text{and} \quad \frac{453.\text{g}}{1.00\ \text{lb}} \qquad \frac{1.00\text{g}}{1.00 \times 10^3\ \text{mg}} \quad \text{and} \quad \frac{1.00 \times 10^3\ \text{mg}}{1.00\ \text{g}}$$

Step 3: Choose the conversion factor to get the answer in milligrams:

$$10.31\ \cancel{\text{lb}} \times \frac{453.6\ \cancel{\text{g}}}{1.00\ \cancel{\text{lb}}} \times \frac{1.00 \times 10^3\ \text{mg}}{1.00\cancel{\text{g}}} = 4.677 \times 10^6\ \text{mg}$$

Matter

What is Matter?

The term "matter" is used to describe things which:

- occupy space (hence possess volume and mass)
- are perceivable by our senses

Matter can be classified in terms of its:

- physical state: solid, liquid, or gas
- chemical composition: element, compound, or mixture.

Chemical Compositions

Element

Elements are composed of one type of atom. Elements are classified as metal, nonmetal or metalloid (semi-metal). (Ex: Copper)

Compound

Compounds are a combination of elements in a definite proportion. The atoms of each of the individual elements are chemically combined to form the compound. The properties of the compound are different from those of the individual elements that it is comprised of. A chemical change can break down a compound into its individual elements. (Ex: Sugar)

Mixture

A non-pure substance made of two or more elements or compounds that can be separated by physical, as opposed to chemical, procedures. (Ex: Antifreeze)

What are Atom?

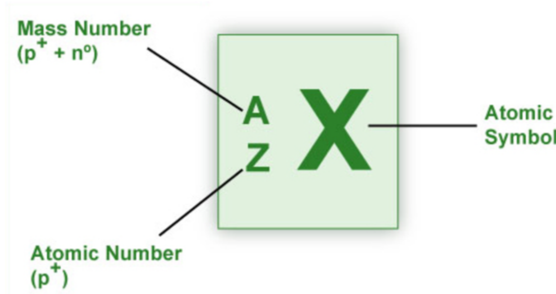
Atoms are composed of electrons, protons, and neutrons. The nucleus of the atom contains the neutrons and protons. The electrons surround the nucleus and are equal to the number of protons in a neutral atom.

Protons have a positive charge (p^+)
Neutrons have no charge (n^o)
Electrons have a negative charge (e^-)

Atomic & Mass Numbers

The **atomic number** of an element (Z) is equal to the number of protons in the nucleus of its atoms. Each element has a different atomic number.

The **mass number** (A) is equal to the number of protons and neutrons in the atom. To calculate the number of neutrons, subtract the atomic number from the mass number:



Number of neutrons = A - Z

Every element has an **atomic symbol** (X). Both the atomic and mass numbers are included with the atomic symbol.

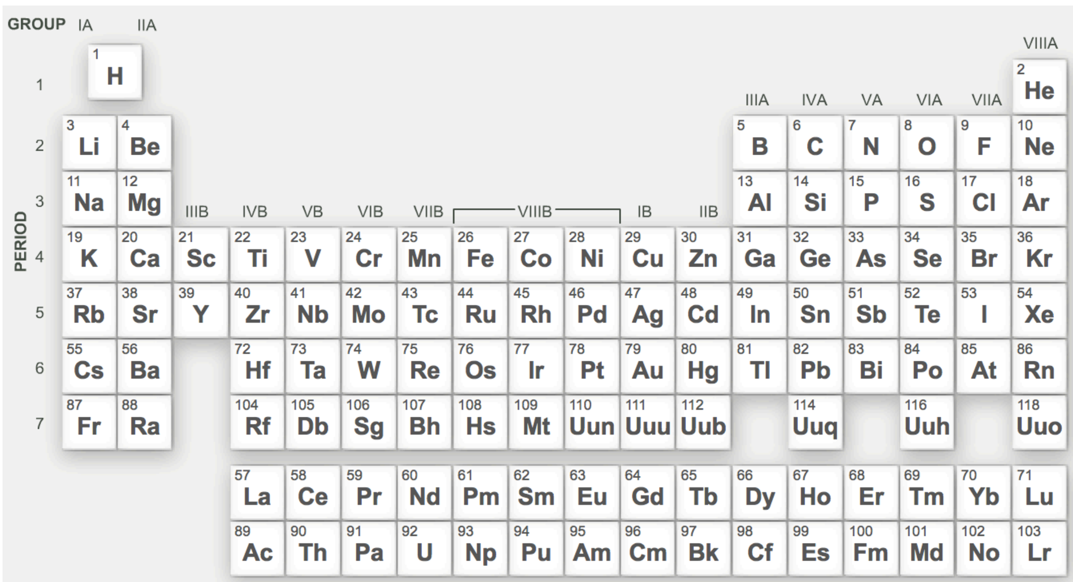
Molecules and Ions

- Molecules: A combination of atoms in a definite proportion e.g., molecule of water (H_2O; hydrogen: oxygen = 2:1).
- Ions: Charged species formed by loss/gain of electron(s) from an atom
- Cation generation: M (g) → M^+(g) + e- (loss of e^-)
  M = metal; g = gaseous state
  [where M^+, a positively charged ion is the cation]
- Anion generation: X (g) + e^- → X^- (g) (gain of e^-)
  X = nonmetal
  [where X^-, a negatively charged ion is the anion]
- Example: NaCl (table salt) a compound, consists of Na^+ (cation) and Cl^- (anion) ions.

Module 3: The Periodic Table and Naming Compounds

The Periodic Table

Fundamentals of the Periodic Table



* Study all of the interactive Periodic Table on the site

Elements

- Elements are arranged into:
    - vertical columns called groups (or families) and horizontal rows called periods
- Elements in the same group (or family) have similar chemical properties. Elements in a period have different chemical properties.
- For each element, the atomic number is given at the top of the symbol and the atomic mass at the bottom.
- The periods are designated with the numbers 1 to 7.

Groups

- The groups are designated with the numbers 1 (I) to 8 (VIII) and a letter A or B.
- A refers to the main-group elements
- B refers to the transition elements
- Group 1A are called alkali metals
- Group 2A are called alkaline earth metal
- Group 7A are called halogens
- Group 8A are called noble (or rare, or inert) gases

Naming Compounds

Classifying Compounds

Chemical compounds are classified as:

- Organic: Compounds that contain at least one carbon atom.
- Inorganic: Compounds that contain atoms other than carbon. Exceptions are inorganic compounds such as carbon monoxide (CO), carbon dioxide (CO_2), etc.

For the purpose of nomenclature (systematic naming), inorganic compounds are classified as those:

- containing a metal and a nonmetal (ionic compounds)
- containing two nonmetals (covalent compounds)

More about Ionic Compounds

Ionic compounds are composed of ions. They are formed by the electrostatic attraction between a positive ion (cation from the metal) and a negative ion (anion from the nonmetal). Electrons are transferred from the atoms of one element to the atoms of another element.

In general, metals lose electrons and nonmetals gain electrons. Ionic compounds are charge neutral (zero net charge). Charges on ions involved in an ionic compound must be known in order to name the compound formed between them or to derive the formula for the compound.

Rules for Naming Ionic Compounds

Rule 1: For metals of Groups 1A, 2A and 3A of the Periodic table, the charge on the formed monoatomic cation is equal to the group number.

The cation has the same name as that of the metal and is always named first.

Common Monatomic Cations

Element symbol	Cation	Cation name
Li	Li^{+}	Lithium
Mg	Mg^{2+}	Magnesium
Aℓ	$A\ell^{3+}$	Aluminum

Rule 2: For nonmetals of Groups 5A, 6A and 7A the charge on the formed monoatomic anion is equal to the group number minus 8.

The anion is comprised of the root of the nonmetal name and ends with the suffix –ide.

Common Monatomic Anions

Element Symbol	Anion	Anion Name
N	N^{3-}	Nitride
O	O^{2-}	Oxide
F	F^{-}	Fluoride

Rule 3: Many metals (particularly transition metals) form more than one cation, the charge specified by roman numerals.

Rule 4: Polyatomic ions consist of two or more atoms bonded covalently possessing a net positive or negative charge.

Ex. Ammonium ion (NH_4^+) is a polyatomic cation
Ex. Carbonate ion (CO_3^{2-}) is a polyatomic anion

Rule 5: When an acid dissociates (breaks up) it produces H^+ ions and a counter ion of equal but opposite charge. (H^+ donors and OH^- bases)

Ex. H_2SO_4 loses one H^+ ion leaving it HSO_4^-
Ex. H_2SO_4 loses two H^+ ion leaving it SO_4^{2-}

Common Polyatomic Ions

Name	Formula
Ammonium	NH_4^+
Bicarbonate	HCO_3^-
Carbonate	CO_3^{2-}
Hydroxide	OH^-
Nitrate	NO_3^-
Phosphate	PO_4^{3-}
Bisulfate	HSO_4^-
Sulfate	SO_4^{2-}

Examples
NaCl → Sodium chloride
Ca_3N_2 → Calcium nitride
Iron (III) nitrate → $Fe(NO_3)_3$
Cu_2O → Copper (I) oxide

Others:
Water (H_2O)
Ammonia (NH_3)
Hydrogen sulfide (H_2S)
Hydrogen peroxide (H_2O_2)
Methane (CH_4)
Ozone (O_3)

Rules for Naming Covalent Compounds

Rule 1: Name the first element in the formula first.
Rule 2: Name the second element as an anion.
Rule 3: Use prefixes to indicate the number of atoms of each element.
Rule 4: Do not use the prefix mono- for the first element.

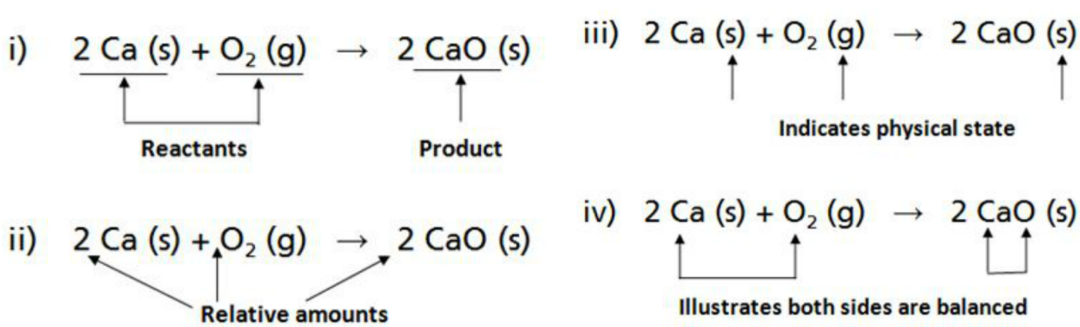
Prefixes used in Naming Compounds	
Prefix	**Number Indicated**
Mono-	1
Di-	2
Tri-	3
Tetra-	4
Penta-	5
Hexa-	6

Examples:
CCl_4 → Carbon tetrachloride
Dioxygen difluoride → O_2F_2

Representation of Chemical Reactions

Chemical reactions are expressed as an equation (chemical equation) using chemical formulas.

i) Identifies the reactant(s) and product(s).
ii) Shows the relative amount of the reactant(s) and product(s).
iii) Indicates the physical state of the reactant(s) and product(s) [s=solid; l=liquid; g=gas; aq=aqueous].
iv) The balanced equation complies with the Law of Conservation of Mass and Matter (atoms and charges on both sides must be balanced).



Writing Chemical Equations

In writing chemical equations:

- (i) Fractional coefficients are avoided
- (ii) Smallest whole-number coefficients are written

Coefficients vs. Subscripts

Coefficients are the numbers written in front of each formula. Whereas the coefficients indicate the moles of reactants and products, subscripts show the number of each atom present.

Ex: $4\ Al\ (s) + 3\ O_2\ (g) \rightarrow 2\ Al_2O_3\ (s)$
Coefficients: 4, 3 and 2
Subscripts: 1, 2, 2, and 3

Subscripts outside a bracket multiply the subscripts inside and the coefficient multiplies every atom in the formula.

Ex: $Pb(NO_3)_2\ (aq) + 2\ KI\ (aq) \rightarrow PbI_2\ (s) + 2\ KNO_3\ (aq)$
Coefficients: 1, 2, 1 and 2
Subscripts: 1, 2, 6, 1, 1, 1, 2, 1, 1, 3
$2\ KNO_3$ represents 2 potassium, 2 nitrogen and 6 oxygen atoms

Balancing Equations

A main point of a balanced equation is that there are the same number of atoms appearing in the reactants (LHS) and the products (RHS).

Phase 1: Balance the following equation (write it out)

$K + H_2O \rightarrow KOH + H_2$

K: 1	K: 1	* Hydrogen is not balanced
H: 2	H: 3	* Note that both K and H_2 are in elemental form
O: 1	O: 1	

Phase 2: Now since hydrogen appears in both H_2O and KOH, begin balancing using these two, more complex, species.

$K + 2\ H_2O \rightarrow 2\ KOH + H_2$

K: 1	K: 2
H: 4	H: 4
O: 2	O: 2

Phase 3: Both H and O are now balanced, but K is not.

$2\ K + 2\ H_2O \rightarrow 2\ KOH + H_2$

K: 2	K: 2
H: 4	H: 4
O: 2	O: 2

So, the balanced equation is: $2\ K + 2\ H_2O \rightarrow 2\ KOH + H_2$

Using Balanced Equations for Chemical Calculations

Balanced equations are used for chemical calculations. As atoms, molecules or ions are the basic units, the coefficients in such equations denote their number.

For example, according to the chemical equation:

$$N_2\ (g) + 3\ H_2\ (g) \rightarrow 2\ NH_3\ (g)$$

- 1 mole of nitrogen molecules consumes 3 moles of hydrogen molecules to yield (to produce) 2 moles of ammonia molecules

If under a set of optimum conditions, solid calcium carbonate decomposes to produce solid calcium oxide and gaseous carbon dioxide, how many moles of carbon dioxide gas will be produced (under similar conditions) from 5.00 moles of calcium carbonate?

$$\mathbf{CaCO_3\ (s) \rightarrow CaO\ (s) + CO_2\ (g)}$$

According to the balanced chemical equation, 1.00 mole of solid calcium carbonate produces 1.00 mole of carbon dioxide gas. Therefore, 5.00 moles of carbon dioxide gas will be produced from 5.00 moles of solid calcium carbonate.

Mole: Can be considered a "packaging unit", a mole always equals to Avogadro's number (6.022×10^{23}).

Atomic Masses: (mass of 1 mole of atoms or mas of 6.022×10^{23} atoms) of elements are given in the Periodic Table.

Molecular Mass/Formula Mass (for ionic compounds)**:** (mass of 1 mole of molecules of mass of 6.022×10^{23} molecules) can be calculated:

Molecular Mass (or Formula Mass) = Sum of Atomic Masses

Ex: Formula mass of calcium nitrate [$Ca(NO_3)_2$]:

Ca: 1 x 40.08 g/mol	= 40.08 g/mol
N: 2 x 14.01 g/mol	= 28.02 g/mol
O: 6 x 16.00 g/mol	= 96.00 g/mol
	164.10 g/mol

Chemical calculations often involve conversion of mass to mole and vice versa. The following expression can be used in performing such conversions:

$$\text{Mole} = \frac{\text{Mass in grams}}{\text{Molar mass (or formula mass)}}$$

Example 1

How many moles are there in 98.0 g of sulfuric acid?

Mole = ?
Mass in grams = 98.0 g
Formula mass (H_2SO_4) = (2 x 1.008) + (1 x 32.06) + (4 x 16.00)
= 98.08 g/mol

$$\text{Mole} = \frac{98.0\ \text{g}}{98.08\ \text{g/mol}} = 0.999\ \text{mole}\ (9.99 \times 10^{-1}\ \text{mole})$$

Example 2

How many grams are there in 2.000 moles of carbon tetrachloride?

Mole = 2.000 moles
Mass in grams = ?
Molecular mass (CCl_4) = (1 x 12.01) + (4 x 35.45)
= 153.81 g/mol

$$\text{Mass in grams} = 2.000\ \text{moles} \times \frac{153.81\ \text{g}}{\text{mol}} = 307.6\ (3.076 \times 10^{2}\ \text{g})$$

Module 4: Hazards in the Work Environment

Occupational Hazards

Types of Hazards

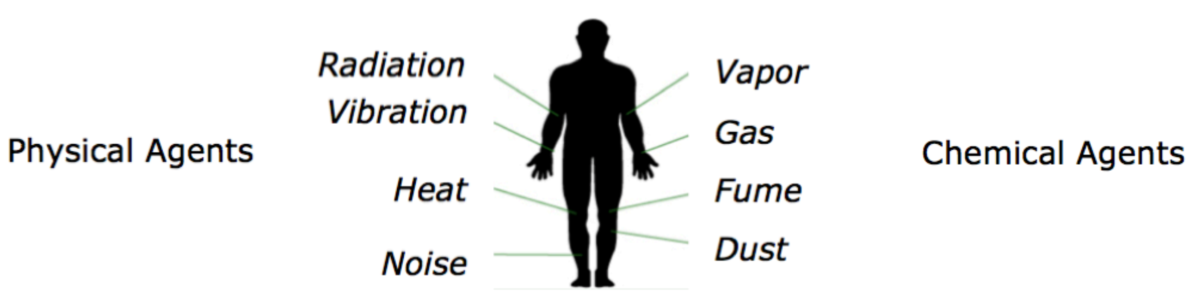
In a workplace, the worker may be exposed to:

Safety hazards	Health hazards
Based on the nature of the work, safety hazards are due to material handling, machines, energy, work practices, and confined spaces. ▪ **Material handling hazards**: These can lead to muscle strains due to lifting and carrying materials. The use of devices such as forklifts, cranes, etc. exposes the worker to accidental contact with the moving equipment. ▪ **Machine hazards:** Rotating shafts, moving belts, presses, etc. can cause very serious injuries. ▪ **Energy hazards:** All energy sources such as electricity, steam, hydraulic pressure, etc. can lead to serious injury. ▪ **Work practice hazards:** Failure to follow safe operating procedures may lead to serious injuries. ▪ **Confined space hazards:** In such spaces (for example, silos, storage tanks, pipelines etc.) hazards arise due to difficulty of entry and exit, build-up of hazardous materials and oxygen deficiency.	The extent of occupational health hazards varies with the type of activity. However, such hazards may have the potential to cause severe discomfort, illness, and lack of efficiency among workers. Based on the nature of the causative agent (or factor), occupational health hazards can be classified as physical, chemical, biological and ergonomic. ▪ **Physical hazards** are due to the presence of physical agents such as pressure and temperature extremes, excessive noise and vibration, and exposure to radiation. ▪ **Chemical hazards** are due to the presence of chemical agents such as dust, fume, gas, mist, smoke and vapor. ▪ **Biological hazards** are due to the presence of biological agents such as bacteria, moulds and viruses. ▪ **Ergonomic hazards** are due to ergonomic stresses such as fatigue and repetitious work.

It is very important to note that the mere presence of a causative agent does not necessarily constitute a hazard. A causative agent is classified as hazardous in certain circumstances such as high concentration or intensity and a prolonged exposure.

Workers have the right to:

- Work in a safe and healthy environment
- Know the processes and substances they are working with
- Know potential hazards from these processes and substances



Physical Agents

Although we are constantly exposed to such agents, their intensity and duration of exposure may be more significant in the workplace. Such agents may cause immediate or cumulative adverse health effects.

Commonly encountered physical conditions with a potential to cause adverse health effects include:

- pressure and temperature extremes
- excessive noise and vibration
- radiation

The action of physical agents consists of transfer of residual energy through the surrounding air or the equipment the worker is in contact with. Except for radiation, our senses can detect all other physical agents.

Pressure and Temperature

Pressure Extremes:

Our bodies are conditioned to work at normal atmospheric pressure. Any extreme can be detrimental to one's health. Two types of abnormal pressure-related conditions are hyperbaric and hypobaric.

Hyperbaric	Hypobaric
Defined as a pressure higher than normal atmospheric pressure. Mining and underwater workers may be exposed to hyperbaric conditions.	Defined as a pressure lower than atmospheric pressure. Encountered by those working at high elevations such as ski instructors and airline pilots.

Temperature Extremes:

The biochemical processes in one's body take place within a very narrow temperature range and hence the regulation of body temperature is an important function. Temperature extremes affect the working efficiency as well as the health of a worker.

- Apart from the surrounding temperature, sensation of hot and cold depends on: air movement, hot or cold objects in the vicinity and relative humidity
- The terms heat stress and cold stress refer to excessive exposure to very hot or very cold work environments. Both such conditions may interfere with worker's performance and may even be fatal.

Heat	Cold
Some of the adverse effects in very hot work environments (depending upon the individual worker and the heat intensity) include: • Heat exhaustion • Fainting • Heat stroke Heat-related problems may arise for: • Outdoor workers (working in construction) • Industrial workers (working near furnaces)	In very cold work environments (depending upon the individual worker and intensity of cold), the adverse effects include: • Frostbite • Hypothermia Workers at risk include: • Outdoor workers (divers) • Meat packers and handlers (working in refrigerated warehouses)

Noise and Vibration

Excessive Noise:

- Noise is a form of irregular vibration. It may be conducted through gases (or vapors), liquids, or solids.
- Above a certain level, the noise becomes of concern because it may hinder communication between workers, thus leading to annoyance.
- This in turn may lead to poor job performance and compromise the safety of the worker.
- Excessive exposure to high noise levels may cause hearing loss.

Excessive Vibration:

- It may cause discomfort however exposure to vibration is more than just a nuisance.
- Intense vibration has been known to cause serious health problems such as back pain, carpal tunnel syndrome (a condition affecting the hand and wrist) and damage to bones and joints.

There are two types of occupational vibration: whole-body and hand-arm vibration.

- Whole-body vibration is transmitted through the supporting surface (feet, back, etc.),
- Hand-arm vibration is transmitted to the hands and arms. Examples include: Mining equipment (whole-body vibration) and Hand-held power tools (hand-arm vibration).

Radiation

- The hazard associated with a particular type of radiation depends on its energy and ability to penetrate the body tissue.
- Even brief exposure to high energy and highly penetrating x-rays can cause severe damage to the tissue.
- Infrared, ultraviolet and microwaves on the other hand do not penetrate appreciably below the skin and the damage is mainly restricted to burns to the skin and eyes.
- Severe damage to eyes may result from excessive exposure to ultraviolet radiation.

Chemical Agents

A large variety of chemical agents are encountered in workplaces due to the diversity of raw materials and processes used.

Chemical hazards in such environments arise due to the presence of certain chemical agents whose properties (physical and/or chemical) and/or toxicity may pose a potential risk to the health and safety of the worker coming in contact with it or handling it.

Operational Hazards

Compressed Gases:

- In the workplace many hazardous chemicals e.g., chlorine gas is compressed and thus stored in cylinders under high pressure. In using such materials, the worker is not only subjected to the chemical hazard but also the hazards associated with pressure extreme.

Flammable and Combustible Materials:

- Such materials may burn readily in the presence of sources of ignition
- Many organic compounds such as gasoline, solvents etc. fall in this category.

Oxidizing Materials:

- These materials can contribute strongly to fire hazards, and may possess the ability to oxidize, and thus destroy, the biomolecules in living systems. Some commonly encountered oxidizers in the workplace include: potassium permanganate, hydrogen peroxide, etc.

Poisonous Materials:

- Such substances may be dangerous to life in very small amounts. For example: potassium cyanide, mercury salts.

Corrosive Materials:

- Such chemicals cause deterioration of materials including living tissues on contact. Some examples are sulfuric acids, potassium hydroxide etc.

Dangerously Reactive Materials:

- The chemicals in this category may undergo rapid or violent reactions under certain conditions. For example, alkali metals react with water producing highly flammable hydrogen gas.

Airborne Hazards

Fine Particles:

- The particles of size less than 5 microns ($5x10^{-6}$ m) are potentially the most hazardous because of their effective entry and retention in the lungs.
- The particles are classified as dust, fume and smoke (for solids), and mist (for liquids).

Sources of fine particles include:

- Spray paining (mist)
- Welding (fume)
- Incomplete combustion of oil and grease (smoke)
- Ore grinding (dust)

Gases and Vapors:

- These may be generated as a result of various operations and can mix and distribute rapidly throughout the workplace. In view of their small size, the gases can readily enter the bloodstream through the lungs.

Some sources of potentially toxic gases and vapors include:

- Solved degreasing (vapors of solvent used)
- Spray painting (vapors of solvent used)
- Welding (gaseous combustion products)

Also:

- *Both as particles and vapors at the same time*
- *Adsorbed or absorbed gases and/or vapors on particles*

Biological Agents

- Biological agents are living organisms, or substances produced by such organisms, that can cause illness or disease in humans.
- The adverse health effects due to biological agents may range from allergic reactions to serious medical conditions and even death.
- Food poisoning, rabies, tuberculosis and hepatitis are some of the infections caused by biological agents.
- These include: bacteria, fungi, viruses and other micro-organisms and their associated toxins.

Workplace Exposure

- Many micro-organisms pose a potential danger in a variety of workplaces due to their ability to reproduce rapidly and survive with minimum resources.
- Workplace exposure to work-related biological agents such as bacteria, molds, and viruses is limited to certain occupations such as health care workers (i.e., hospital workers and veterinarians), meat handlers (i.e., ranchers, farmers, and meat packers), and those who work in sanitation or sewage operations.

Hazard Assessment

In order to recognize and assess the potential impact of occupational hazards, walk-through surveys are performed. Such surveys generally include a study of the following parameters in terms of their impact on the surrounding environment and thus the workers.

Processes, Operations and Related Activities

Generally various emissions are evaluated because the emission of any physical, chemical or biological agents has the potential to be a health hazard.

Equipment

Equipment is generally assessed in terms of mechanical and electrical safety and the potential to create excessive noise and vibration.

Properties of Substances Used and Produced

These include and evaluation of raw materials and finished products in terms of their physical, chemical and toxic properties and effects.

Control Measures

All engineering controls in place for proper materials handling, storage, etc. are evaluated. Also considered are the ventilation system and the availability of personal protective equipment.

Ergonomic Stresses

Ergonomics can be defined as the science or study of work. It is a way of designing a work environment to fit people.

Over the recent years it has been fully realized that the traditional method of assigning people to jobs without accommodating their needs, limitations, sizes, strengths and weaknesses may lead to certain adverse job safety and health issues such as mental stress, loss of efficiency and accidents.

It has been established that ergonomics, properly applied, can help:

- reduce workplace injuries and illnesses; particularly back injuries and cumulative trauma disorder (CTD) affecting, joints, muscles, nerves and tendons that can cause pain and swelling
- improve productivity and quality of work
- increase job satisfaction
- satisfy government regulations

Toxicology

What is Toxicology?

Toxicology is the science that involves the study of the properties and interactions of physical, chemical or biological agents.

Toxicity is the degree of danger of a material to injure a living organism by other than mechanical terms.

Toxic hazards posed by a chemical are influenced by a number of factors such as:

- Physical properties
- Chemical properties
- Intensity of exposure (exposure dose) [concentration x duration of exposure]
- Mode of handling
- Routes of entry
- Susceptibility of the worker

Properties and Interactions of Physical/Chemical/Biological Agents

Respiratory, Digestive & Cutaneous:

- The interaction of physical, chemical or biological agents may reproduce adverse responses with our bodies. Such responses may range from minor irritation to dreaded diseases like cancer.

Most common natural routes of entry of chemical agents into the body include:

Respiratory tract (by inhalation)
Digestive tract (by ingestion)
Cutaneous - skin and eyes (by absorption)

In occupational settings, inhalation is the most important route followed by absorption through skin and eyes.

Dose and Exposure

Dose

Dose is defined as the amount of toxicant(s) actually delivered to the target organ. The units used to express dose are mg/kg (mass of toxicant/body mass).

Exposure

Exposure on the other hand is the total amount of the toxicant(s) present in the workplace. However, exposure does provide an indication of the dose. Higher the exposure, greater the probability of larger amounts being delivered to the target organ and hence higher the dose.

The units used to express exposure are:

- mg/m^3 and $\mu g/m^3$ (mass of toxicant/volume of air) for particles
- ppm (parts per million), ppb (parts per billion) and percent (%) for gases and vapors

Threshold Limit Values

In order to provide guidelines for controlling occupational health hazards, Threshold Limit Values (TLVs) for various physical and chemical agents have been developed by the American Conference of Governmental Industrial Hygienists (ACGIH).

According to ACGIH, one of the ways to specify these values is as Threshold Limit Value-Time-Weighted Average (TLV-TWA). It is the time-weighted average concentration of a substance for a normal 8-hour workday and a 40-hour workweek to which nearly all workers may be repeatedly exposed, day after day, without adverse effects.

Therefore, the lower the TLV value, the more potentially dangerous (or high risk) the substance is.

The Effect of Toxicants

Classification for the effects of over exposure to toxicants (or the commonly used term contaminants) can be based upon:

- Duration of the effect
- Organs affected and physiological action

Duration of the Effect

Acute Effect:

The observed effect of a toxicant is considered acute if it appears soon after exposure. The effect generally results from brief exposure to a high concentration of the contaminant. The effect is also easy to observe and relate.

Chronic Effect:

The effect is considered chronic if it is observed much later after exposure. Chronic effects result from low and repeated exposure over a long period of time; they may have latency periods. Chronic effects are more difficult to study and are very important to consider when dealing with hazardous wastes and pollution.

Psychological Effects

The toxicant may change the normal functioning of one organ or a set of organs that operate as a system.

- Hepatotoxins (e.g., carbon tetrachloride) affect the liver.
- Immunotoxins (e.g., vinyl chloride) act upon the immune system.
- A variety of physiological effects have been observed due to the diversity of contaminants in the workplace.
- Based upon the observed physiological effects, the chemicals are classified.

Observed Physiological Effects:

- **Asphyxiants**: Such chemicals hinder the body in maintaining an adequate supply of oxygen. This leads to suffocation due to lack of oxygen. Examples: carbon monoxide and cyanides.
- **Irritants:** These substances cause eye, skin, and mucous membrane irritation. Examples: ozone, hydrogen sulfide.
- **Anasthetics:** These act as depressants. Examples: chloroform, alcohols.
- **Narcotics:** Such chemicals are habit forming depressants. Examples: morphine, Demerol.
- **Systemics:** These cause organ(s) or system(s) damage. Examples: benzene, phenol.
- **Lung scarring agents:** Such materials can cause lung damage leading to lung cancer. Examples: mineral dust, asbestos.

Carcinogenic Effect:

- **Carcinogens:** These chemicals cause cancer. Examples: ethylene dibromide, vinyl chloride.
- Carcinogens are identified by their ability to cause cancer in exposed workers, other human populations, or in test animals.
- Many occupational cancers have a long latency period.

Mutagenic Effect:

- **Mutagens:** Such substances cause changes in DNA of cells from people or test animals, which may result in disease or abnormalities in future generations. Examples: benzene, ethylene oxide.
- In WHMIS, mutagens are classified as VERY TOXIC if they are shown to affect cells of the reproductive system (sperm and egg cells - the cells from which children develop).
- Mutagens are classified as TOXIC if studies show genetic changes only in cells (e.g. skin or lung cells) that are not part of the reproductive system.

Teratogenic Effect:

- **Teratogens:** These chemicals cause malformations in newborns. Examples: organic mercury compounds, anesthetic gases such as nitrous oxide.
- Teratogens and embryotoxins can cause birth defects, abnormalities, developmental delays, or death in animal offspring in the absence of significant harmful effect on the mother. These materials are usually identified using test animals and may cause similar effects in humans.

W.H.M.I.S.

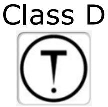
Workplace Hazards

- Studies estimated a high social cost due to exposure to hazardous materials in the workplace. Due to the seriousness of such health & safety problems, it was agreed to implement an information system with the goal of reduced incidence of illnesses and injuries caused by the hazardous materials in the workplace.
- The Workplace Hazardous Materials Information System (WHMIS) is a Canada-wide system developed over several years through the collective efforts of Labor, Industry, and Federal, Provincial, and Territorial Governments. Published in January 1988, it became legislation in October 1988.

The system consists of three key elements:
- cautionary labeling of containers of hazardous materials
- provision of Material Safety Data Sheet (MSDS), which provides more detailed information on the hazardous nature of the material
- provision of worker education program

Hazard Symbols

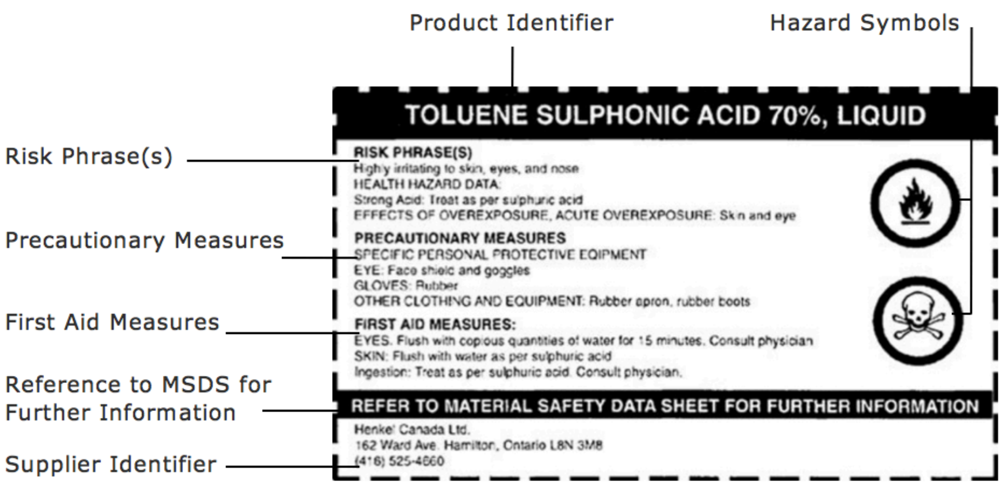
According to W.H.M.I.S. hazardous materials are divided into classes:

Class A 	Compressed Gas • Contents under high pressure • Cylinder may explode or burst when heated, dropped or damaged
Class B 	Flammable and Combustible Material • May catch fire when exposed to heat, spark or flame • May burst into flames
Class C 	Oxidizing Material • May cause fire or explosion when in contact with wood, fuels or other combustible material
Class D 	Division 1: Poisonous and Infectious Material (Immediate and serious toxic effects) • Poisonous substance • A single exposure may be fatal or cause serious or permanent damage to health
Class D 	Division 2: Poisonous and Infectious Material (Other toxic effects) • Poisonous substance • May cause irritation • Repeated exposure may cause cancer, birth defects, or other permanent damage

Class D 	Division 3: Poisonous and Infectious Material (Bio-hazardous Infectious materials) • May cause disease or serious illness • Drastic exposures may result in death
Class E 	Corrosive Material • Can cause burns to eyes, skin or respiratory system
Class F 	Dangerously Reactive Material • May react violently causing explosion, fire or release of toxic gases, when exposed to light, heat, vibration or extreme temperatures

Container Labels

The following information must appear on a standard supplier label placed on a container of hazardous material:



Safety Data Sheet

The Material Safety Data Sheet (MSDS) provides basic information on a chemical product.

It contains information regarding its:

- Properties
- Potential hazards
- Safe use
- Emergency procedures

It is important to note that these are not a complete source of information. In some cases, it might be necessary to consult other relevant sources for further information and details on a given substance.

Implementation

Workers handling hazardous products must be instructed in:

- The information on labels and MSDSs as it applies to their work
- Safe use, handling, storage and disposal of hazardous materials
- Emergency procedures to be used in case of a spill or overexposure

Successful Implementation Requirements

Successful implementation of WHMIS in the workplace requires cooperation of all parties involved. WHMIS sets the responsibilities of the parties involved:

- **Suppliers:** provide hazard information through labels and MSDS on all controlled products/containers of controlled products.
- **Employers (Supervisors)**: ensure WHMIS labels, identifiers and MSDSs for all containers of controlled products. Employers also ensure availability and accessibility of MSDS information to employees and provide effective worker training to ensure understanding among employees of the labels, MSDSs, and precautionary measures for hazardous materials in their workplace.
- **Employees:** handle controlled products safely and inform supervisors of damaged/missing labels and missing MSDS information.
- **Regulators:** develop and administer WHMIS legislation.

Globally Harmonized System (GHS)

The (GHS) is for hazard classification and labelling. Systems similar to WHMIS (for hazard communication) exist in other countries.

In 1992, the United Nations Conference on Environment and Development (UNCED) agreed to develop a Globally Harmonized System (GHS) for hazard classification and labelling. It is anticipated that such a system will facilitate safe use of chemicals and reduce trade barriers.

Some of the anticipated changes are:

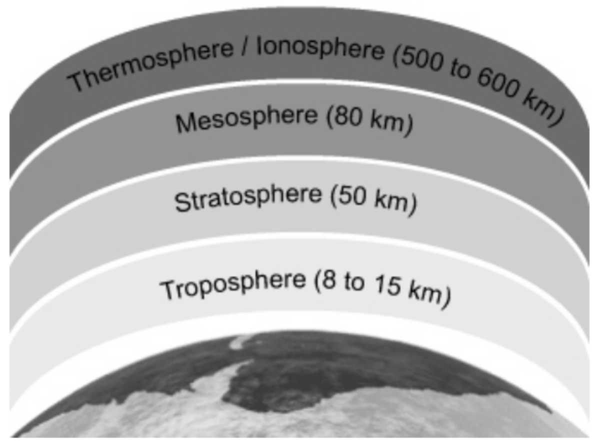
- Inclusion of consumer, transport and workplace sectors rather than workplace only.
- Inclusion of all chemicals except pharmaceutical and cosmetic products intended for consumer use.
- Hazard classification format in the MSDSs.
- Hazard communication format in the labels.

Module 5: Air and Water

Air

The Air We Breath

Air (which all of us must breathe) composes the atmosphere and is a complex mixture of gases surrounding the Earth. The atmosphere is a layered structure divided into layers according to a variety of criteria such as gradually changing:



- Altitude (how the layers of the atmosphere are divided)
- Pressure
- Temperature
- Electrical nature
- Chemical composition and concentration

Composition of Air

The air we breathe is a mixture of several gases, fine particles and vapors. Dry air consists of 21% oxygen and 78% nitrogen plus traces of other substances that are both natural and human-made.

- Major components of air: nitrogen (N_2), oxygen (O_2), water (H_2O) and carbon dioxide (CO_2)
- Some minor components of air: carbon monoxide (CO), ozone (O_3), oxides of sulfur (SO_x) and oxides of nitrogen (NO_x)

The Air Pollutants

- Whereas major components are essential for life, the minor components are pollutants, which under certain conditions may produce adverse environmental and health effects.

- These air pollutants are emitted directly into the atmosphere during combustion and production processes, changing the composition of atmosphere and causing poor air quality.

The burning of fossil fuels (i.e., petroleum, natural gas and coal) can be used:

- to generate energy (electricity, gas and steam)
- in transportation (combustion engines)
- in industrial processes that use a great deal of energy sources (i.e., pulp and paper mills, ore smelters, petroleum refineries, power generating stations and incinerators)

These elements are mainly responsible for the presence of minor components; they are the major sources of human-created air pollution.

Minor Components

What is Carbon Monoxide?

- When there is an adequate supply of oxygen, there is complete combustion of fossil fuels thereby forming the major by-products: carbon dioxide and water.
- Most carbon monoxide (CO) produced in this process is immediately oxidized to carbon dioxide.
- However, when there is an insufficient supply of oxygen, there is incomplete combustion of fossil fuels and carbon monoxide gas is released.
- Carbon monoxide can also be produced by other processes such as combustion of organic matter during waste incineration.
- Natural sources of carbon monoxide include forest fires and volcanoes.
- When a person inhales carbon monoxide, it binds to the oxygen-carrying site on the hemoglobin of red blood cells, causing a reduction of oxygen transport in the body. This is because the hemoglobin can no longer take up oxygen from the air, resulting in cell and tissue death.

→ The health effects associated with exposure to carbon monoxide include: impaired ability to use oxygen, decreased athletic performance and cardiac problems.

What is Ground-level Ozone?

- Ozone (O_3) is a naturally occurring gas that forms a protective layer in the atmosphere, present predominantly in the stratosphere. Ozone serves to protect the Earth by absorbing harmful ultraviolet radiation from the Sun.

- Ground-level ozone is produced during photochemical reactions between volatile organic compounds (VOCs) released in automobile exhaust and oxides of nitrogen (NO_x) in the presence of sunlight. Ozone is also generated in industrial processes such as arc welding.

→ The health effects associated with exposure to ground-level ozone include: damaged biological tissues and cells, reduced lung function, breathing difficulties and itchy, burning and watery eyes.

What are Oxides of Sulfur?

- Oxides of sulfur (SO_x) are released mainly during processing (smelting) of mineral ores and the combustion of fossil fuels (i.e., burning of coal/petroleum).
- Many industrial processes such as pulp and paper production and petroleum refining also generate oxides of sulfur. Such emissions include sulfur dioxide (SO_2) and sulfur trioxide (SO_3).
- Further reactions in the atmosphere may lead to the formation of sulfuric acid (H_2SO_4) and sulfate (SO_4^{2-}) salts. The most common natural source of sulfur dioxide is volcanoes.

→ The health effects associated with exposure to high levels of oxides of sulfur include: problems breathing (particularly for asthmatic people) and respiratory illness.

What are oxides of Nitrogen?

- Some sources of the emission of oxides of nitrogen (NO_x) include: fuel combustion for transportation, home, and industrial use; manufacture of nitric acid; welding, etc.
- Oxides of nitrogen form in the air because fuel is burnt at high temperatures. This is mostly in the form of nitric oxide with a small amount as nitrogen dioxide (usually less than 10%).
- Once emitted, nitric oxide (NO) is oxidized, forming nitrogen dioxide (NO_2). In addition, nitric acid (HNO_3) and nitrate (NO_3) salts may be formed due to further reactions.
- The main oxides of nitrogen present in the atmosphere are nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O).
- Nitrogen oxides are also emitted from natural sources including lightning and microbial activity of soil bacteria.

→ The health effects associated with exposure to oxides of nitrogen include: serious lung damage and shortness of breath and chest pains.

Assessing Health Risks

Entry into the Body

- The air we breath (inhalation) is handled by the lungs, which provide an extremely efficient method of getting oxygen (required for metabolic processes) into and carbon dioxide (waste product of metabolic processes) out of the body.
- Unfortunately, the lungs also provide an excellent opportunity for minor components (pollutants) to diffuse into the blood stream via gas exchange in the alveoli.
- As breathing is a continuous process, considerable amounts of a pollutant (even if present as a minor component) can be inhaled and efficiently transported into the body. Once in the body, they may manifest adverse health effects.

Risk Assessment

In order to assess the health risks due to air pollutants, we require exposure and effects assessment.

- Exposure assessment: estimates concentrations using chemical measurements.
- Effects assessment: relies on toxicity testing (estimates of exposure toxicity) and computer models to extrapolate data from human population, animal, and bacterial toxicity studies. Quantitative analysis of epidemiological, toxicological and exposure data that are based on the accurate scientific evidence estimates exposure toxicity and risk.

Risk characterization integrates the exposure and effects components to estimate the risk.

Exposure Measurement

Exposure is measured by determining the pollutant concentration in air. Monitoring methods include:

- Air sampling followed by laboratory analysis of the pollutant(s) using established procedures.
- Real time monitoring using direct reading pollutant-specific monitors.

For gases and vapors:	For particles:
▪ Parts per million (ppm) ▪ Parts per billion (ppb) ▪ Percent (%)	▪ Milligrams per cubic meter (mg/m^3) ▪ Micrograms per cubic meter ($\mu g/m^3$)

Keep in mind these useful conversion factors:

- $1\% = 10^4$ ppm
- $1 \text{ ppm} = 10^3$ ppb

Example 1

A gas is toxic at a concentration of 500. ppm and any level of exposure above this value is considered unsafe for a worker. A real time monitor for the gas indicated a concentration of 0.0615% in a workplace environment. Is it safe to work in such an environment?

$$\frac{0.0615 \text{ parts gas}}{10^2 \text{ parts air}} \times 10^6 \text{ parts air} = 615. \text{ ppm} \quad \text{NOT SAFE}$$

- Note: x% simply means x parts per hundred parts

Example 2

In an office environment, sampling and subsequent analysis for carbon monoxide (CO) indicated a concentration of 9.0×10^3 ppb. Express the concentration in the units of ppm and %.

$$1 \text{ ppm} = 1 \times 10^3 \text{ ppb}$$

$$(9.0 \times 10^3 \text{ ppb}) \times \frac{1 \text{ ppm}}{1 \times 10^3 \text{ ppb}} = 9.0 \text{ ppm}$$

$$\frac{9.0 \times 10^3 \text{ parts CO}}{10^9 \text{ parts air}} \times 10^2 \text{ parts air} = 9.0 \times 10^{-4}\%$$

Threshold Limit Values

Threshold Limit Values (TLVs) have been developed and issued by the American Conference of Governmental Industrial Hygienists (ACGIH) to assist in the control of workplace health hazards.

- According to ACGIH, Threshold Limit Value-Time-Weighted Average (TLV-TWA), is defined as the time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

Substance	TLV-TWA
CO	25 ppm
NO_2	3 ppm
O_3	0.1 ppm
SO_2	2 ppm

Air Quality and Indoor Air Contaminants

Air quality problems in many other parts of the world are much worse than in Canada. This had led to some global concerns about our environment. It is important to note that in addition to the minor components, we are exposed to a large variety of environmental contaminants in industrial, commercial and residential areas.

Asbestos Fibers

Asbestos (a mineral finer) has been used in a variety of building construction materials for insulating and fire proofing. Deteriorating, damaged, or disturbed insulation, fireproofing, etc. become the source of asbestos fibbers in the indoor air.

Biological Contaminants

Common biological contaminants include: bacteria, dust mites, insects, mold, pet dander, rodents, viruses etc.

Combustion By-Products

These include gases (e.g. carbon monoxide, carbon dioxide, nitrogen dioxide, unburned hydrocarbons etc.) and small particles. These are created by incomplete burning of fuels (e.g., wood, gas, coal etc.) in appliances such as wood stoves, gas stoves, fireplaces etc.

Formaldehyde

The sources of formaldehyde in indoor air include: pressed wood products such as hardwood plywood wall paneling, particleboard, fiberboard etc., furniture made with these pressed wood products, combustion sources, tobacco smoke, textiles and glues.

Pesticides

These originate from the products used to kill household pests (insecticides, disinfectants etc.) In addition, pesticides used on lawns and gardens can be drift or tracked indoors.

Radon Gas

It is slowly released from the ground, water, and some building materials that contain very small amounts of uranium, such as concrete, bricks, tiles etc. Radon can enter a house through cracks in the foundation walls and in floor slabs, floor drains, sumps etc.

Respirable Particles

Depending upon the size these can be inhaled all the way into the lungs. Indoor sources of such particles include: fireplaces, wood stoves, oil heaters, tobacco smoke etc.

Volatile Organic Compounds (VOCs)

These compounds originate from a variety of indoor sources such as air fresheners, aerosol spays, disinfectants, dry-cleaned clothing, hobby supplies, paints, solvents etc.

Control Strategies

Over the past two decades, stricter environmental emission control regulations and pollutant(s) mitigation (reduction) technologies have led to considerable reduction in the concentration of many pollutants.

The North American Free Trade Agreement (NAFTA) obliges all the three signatories to enforce environmental laws. There is a move in all the three nations toward tougher and thorough reporting of releases of pollutants to the environment. In Canada, National Pollutant Release Inventory (NPRI) is a publicly-accessible database of pollutants released to the Canadian environment.

Among the global initiatives is the establishment of the International Register of Potentially Toxic Chemicals (IRPTC). It is a computer based database. One of the objectives of the register is to identify the potential hazards of using chemicals and to make people aware of them. The database provides access to information regarding production, distribution, release and disposal of hazardous chemicals. The database also includes information on environmental and health effects of such chemicals.

Water

The Water Molecule

Water (H_2O) consists of two nonmetals hydrogen and oxygen. The water molecule is formed by the covalent bonding of two hydrogen atoms to an oxygen atom. Water is a unique substance that is literally everywhere. A vital substance to our well-being and very existence, water is intimately linked to our daily life.

Unique Properties of Water

The polar nature and the capability to form hydrogen bonds are responsible for many of the unique properties of water. Such properties play an important role in making water essential for life and in determining its chemical behavior in the environment.

We use water for various purposes, such as: cooking and drinking, personal hygiene, recreation, agriculture, transportation and energy generation.

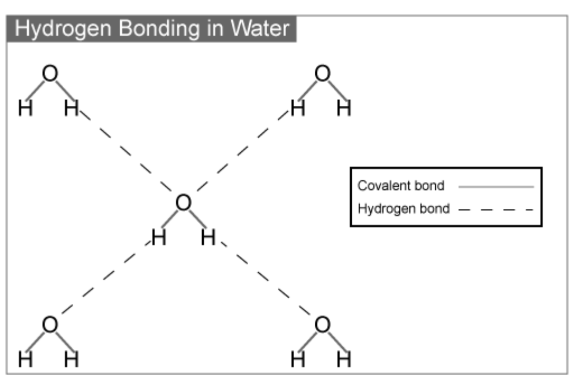
Polarity of Water

The polar nature of the water molecule is due to its:

- Polar covalent bonds: The electron pair forming the covalent bond (between the oxygen atom and each of the two hydrogen atoms) is more strongly attracted by the oxygen atom due to its higher electronegativity (the ability of an atom in a molecule to attract shared electrons over another atom in the molecule).
- This leads to a partial positive charge on each of the two hydrogen atoms (represented as δ^{+}) and a partial negative charge on the central oxygen atom (represented as δ^{-}) making the water molecule behave like a dipole.
- Molecular shape: A water molecule has a bent (V-shape) shape (H-O-H bond angle of 104.5°). This, in combination with the polar covalent bonds, leads to a resultant dipole and hence the polarity of the water molecule.

Hydrogen Bonding

The partial charges present lead to intermolecular attraction between water molecules. A single water molecule can thus attract four other water molecules. These intermolecular attractive forces are called hydrogen bonds. These are much weaker than the forces holding the atoms in the covalent O-H bond.



Solvent Properties

- Water is a powerful solvent due to its high polarity and hydrogen bonding ability.
- It is an excellent solvent for ionic (e.g., table salt), polar covalent (e.g., sugar) and non-polar (e.g., oxygen) compounds.
- In the case of ionic compounds, the ions are separated from the solid and caged (solvated) by polar water molecules, thus keeping them in solution.
- Polar covalent compounds (i.e., ethanol and glucose) dissolve in water by the formation of hydrogen bonds.
- Water therefore plays an important role in the transportation of nutrients and waste products in biological processes.
- Aquatic life and plants survive due to dissolved oxygen and carbon dioxide.

Thermal Properties

The presence of hydrogen bonds in water accounts for its exceptionally high boiling point, specific heat and heat of vaporization. A portion of the heat supplied is used up in breaking the hydrogen bonds.

- **Specific heat** is defined as the amount of heat energy required to increase the temperature of 1 g of a substance by 1°C.

    High specific heat of water regulates and stabilizes the temperatures of geographical regions and organisms within a narrow range. This in turn allows our planet to support life.

- **Heat of vaporization** is defined as the quantity of heat required for the conversion of 1 g of a liquid entirely into its vapor at a constant temperature. High heat of vaporization of water helps in regulating the temperature of our body. It is also responsible for powering the winds and storms of our planet.

Water Density

Ice has a hexagonal open structure due to the presence of hydrogen bonds. When ice melts, the open spaces are filled with liquid water, causing the crystal structure to break down.

This leads to a reduction in volume for the same mass and hence an increase in density (density = mass/volume).

The higher density (thus expansion and contraction of volume due to the freeze-thaw cycle) of liquid water than that of ice accounts for phenomena such as:

- Floating of ice on water
- Survival of aquatic life during winter
- Nutrient turnover in bodies of water
- Formation of pebbles, soil and sand
- Bursting of frozen water pipes

Surface Properties

The high **surface tension** and capillarity of water is due to the presence of hydrogen bonds. Water is the liquid with the highest surface tension. Plant debris rests (rather than sinks) on the surface of water bodies due to its high surface tension. This provides aquatic life with much-needed shelter and nutrients. **Capillary action** (also due to high surface tension) makes water in soil available to plants.

Module 6: Household Products

Soaps and Detergents

What are Surfactants?

Surfactants are composed of a hydrophilic (water-soluble) head and a hydrophobic (fat-soluble, water-hating) tail. The hydrophilic end is stable when solubilized in water and the hydrophobic end consists of a long chain hydrocarbon that is more stable when surrounded by other organic groups.

- Soaps and detergents are composed of surfactants.
- Surfactants are water-soluble and surface-active agents.

Classes of Surfactants

There are different classes of surfactants categorized by the charge of the hydrophilic component of the surfactant molecule after dissociation in water:

- Anionic surfactants have a negative charge.
- Cationic surfactants have a positive charge.
- Non-ionic surfactants have no charge.
- Amphoteric surfactants have both positive and negative charges.

All About Soap

Composition and Limitations of Soap

Soaps (anionic surfactants) consist of the long hydrocarbon tails of fatty acids and the polar heads of sodium or potassium salts of fatty acids (found in fats and oils of animals and plants).

Advantages

- Soaps are manufactured from combinations of natural and renewable resources.
- Soaps are biodegradable and thus do not pollute bodies of water.

Disadvantages

- Poor adaptability to diversity of fibers, washing temperatures and water conditions.
- Tendency to clog sewage systems due to their gelling properties.

- Formation of soap film (or scum) in water containing Ca^{2+} and Mg^{2+} ions (hard water). The calcium and magnesium ions react with soap molecules to produce calcium and magnesium salts of fatty acids. These salts are insoluble in water and impair the surfactant properties of soap because the amount of soap available for cleaning is reduced. Soap scum is difficult to rinse away and can be visible, i.e., on fabrics, bathtubs and sinks.

All About Detergents

Composition and Limitations of Detergents

Detergents (containing a variety of engineered anionic or non-ionic surfactants) are made from petrochemicals.

Advantages

- Detergents are less affected by calcium and magnesium ions in water, thus acting as better cleaning agents and almost eliminating the film formation.
- Detergents perform well under diverse conditions such as adaptability to diversity of fibers, washing temperatures and water conditions.

Disadvantages

- Detergents are made from non-renewable petroleum-based oils.
- Majority of detergents are not biodegradable.

The Cleaning Process

The Soap/Detergent Chemical Interaction

In the cleaning process, the polar end of the surfactant molecule interacts with water (a polar molecule) and the non-polar end is attracted to oil or grease (non-polar molecules).

Step 1. Chemical Interaction (with soap or detergent) traps the oily and greasy soil molecules. In aqueous solution, surfactants cluster near the surface.

Step 2. The hydrophobic tails are attracted to grease and the hydrophilic heads to the water, thereby forcing the grease away from the soiled surface.

Step 3. The grease is then surrounded by the individual surfactants molecules and removed from the soiled surface.

Step 4. Thermal Interaction (with hot water) helps dissolve oil and grease molecules. Mechanical Interaction (machine agitation or hand rubbing) releases oily and greasy soil from the fabric.

Classifications

Depending upon the function, household soaps and detergents can be classified as those used for: personal hygiene, laundry, dishwashing and household cleaning.

It is important to note that in view of the functional diversity, these products are usually formulated by mixing many ingredients. For example, laundry detergents are formulated from the following groups of chemicals:

- Surfactants to bind and suspend grease and dirt in the washing water
- Builders to remove Ca^{2+} and Mg^{2+} from hard water and soil
- Bleaching agents to remove stains and kill bacteria
- Enzymes to catalyze the degradation and elimination of some stains
- Miscellaneous chemicals such as foam stabilizers, fabric brighteners, fragrances, corrosion inhibitors etc. are added in small quantities.

Environmental Impact

It is very important to be aware of the impact on our health as well as the impact on the environment once discharged.

Health risks are very real, particularly in the case of some specialty household cleaners. Drain openers, oven cleaners and toilet bowl cleaners may contain reactive and/or corrosive chemicals. It is imperative that adequate safety precautions are taken while using such products.

The manufacturers are obliged by law to evaluate the environmental safety of the ingredients. Most of these products are formulated to work with water and end up in wastewater treatment plants, thus impact on the environment is minimized.

The **Safer Detergent Stewardship Initiative (SDSI)** program of the U.S. Environmental Protection Agency (EPA) recognizes corporate environmental leaders using safer surfactants which break down quickly into non-polluting chemicals and thus protect aquatic life.

In an effort to handle these products in an environmentally wise way, we as consumers should buy them in usable amounts and dispose of them (if required) properly.

Recent Trends

In keeping with consumer demand for more efficient and environmentally friendly products, the present trend is to develop home and fabric care products that:

- Contain surface protectors or modifiers that repel soil and stains more effectively.
- Deliver active ingredients in a controlled way.
- Are effective in cold water.
- Contain natural or naturally derived ingredient(s).
- Do not contain chemicals of concern with respect to toxicity.
- Generate less carbon dioxide during production (smaller environmental footprint).

Personal Care Products

Influencing Factors

Nearly all of us use personal care products for one or more reasons: to make our hair clean and colorful, skin free of wrinkles or to delight the senses. This is an expanding and dynamic field primarily because such products must be developed to take care of the changing needs of society.

Some influencing factors include:

- Aging population
- Changing attitudes of men
- More women in the workplace
- Concern about exposure to ultraviolet radiation

The chemical ingredients in these products are thus changing at a remarkably fast pace. The availability of biotech products and processes to produce new ingredients is going to revolutionize the development of personal care products in the future.

In addition to rapidly changing chemical ingredients, more efficient delivery systems are being introduced. These include a variety of encapsulation systems to deliver the active ingredients in cosmetics.
Many shampoos, lipsticks, face creams and toothpastes contain these microcapsules. The active ingredient is delivered when the microcapsules rupture on the applied surface (e.g., skin) due to rubbing, presence of moisture, change in pH or the presence of naturally occurring bacteria.

Hair Care Products

Shampoos

Shampoos are cleansing agents containing anionic surfactants to remove oil and dirt from the hair and scalp. Surfactants produce foam, lifting the oil and dirt from the hair. In addition, fragrances, thickeners, foam boosters and other agents may also be added.

Conditioners

Conditioners usually contain cationic surfactants. These help in rinsing out any residual shampoo and at the same time provide softer and easy-to-manage hair.

Styling Agents

The curling of hair is carried out in three steps:

- Treatment of hair with a reducing agent (an electron donor) that breaks certain covalent bonds;
- Setting hair in the desired shape;
- Treating hair with an oxidizing agent (an electron acceptor) such as dilute solution of hydrogen peroxide to reform the previously broken covalent bonds in the new shape.

Colorants

Hair coloring is a two-step process involving:

- Oxidation of natural hair pigments to colorless products using a bleaching agent;
- Application of an organic, synthetic dye to obtain the desired color.

In addition to the dye (or it precursor), the formulations contain ammonia, hydrogen peroxide and a surfactant. In order to reduce the damage to hair during the coloring process and reduce the smell of ammonia, the chemistry has been modified by replacing ammonia with ammonium carbonate.

Major developments in the field of hair coloring include the availability of:

- A large variety of colors.
- Improved delivery systems to enhance the adhesion of colors to the hair.
- More effective conditioners to neutralize the harsh effects of dye chemicals.

Skin Care Products

Moisturizers

Moisturizers are used to increase the water content of the skin. They perform a number of functions such as:

- Prevent and treat dry skin
- Protect the skin and make it appear smooth by encouraging an orderly shedding process.
- Improve skin tone and texture.
- Protect sensitive skin and mask imperfections

The active ingredients in skin moisturizers include:

- Humectant: Absorb moisture and hold it in the skin. Examples: Glycerin, Urea
- Emollients: Lubricate and smooth the skin. Examples: Lanolin, mineral oil
- Miscellaneous: Antioxidant, fragrances, minerals, plant extracts, vitamins

Skin care products (creams, lotions, shampoos and sync are products) containing plant-derived chemicals are being developed at a very fast rate.

Sunscreens

Sunscreen products are used to protect the skin against the harmful effects of ultraviolet (UV-A and UV-B from the sun) radiation.

- Although stratospheric ozone layer destroys most of this radiation, the UV light the gets through can cause problems.
- The depletion of ozone layer due to a variety of natural and human made chemicals may increase the amount of UV radiation reaching us.
- It is believed that exposure to UV radiation can cause painful sunburn, damage the skin, and lead to skin cancer.
- Sunscreen products (sold as lotions, ointments, creams and gels) are formulated with additional chemical ingredients that absorb UV radiation.

Two types of active ingredients commonly used in sunscreens can be classified as:

- Inorganic: Approved for use are titanium dioxide and zinc oxide. These work primarily by reflecting and scattering UV light.
- Organic: Wide varieties are approved for use. These work primarily by absorbing UV light and dissipating it as heat.

The effectiveness of a sunscreen in a formulation is rated by its ability to block the UV-B rays that cause skin burns. It is called Sunburn Protection Factor (SPF). The higher the SPF, the better is the protection against UV-B rays.

Sunscreens: Some Misconceptions

There is a misconception that a user can determine the duration of effectiveness of a sunscreen by multiplying the SPF by the time it takes for him or her to suffer a burn without sunscreen.

In practice, however, the protection from a particular sunscreen depends on the following factors:

- Activities (e.g., swimming leads to a loss of sunscreen from the body)
- Amount applied and frequency of re-application
- Solar intensity
- Type of skin
- Amount of sunscreen absorbed by the skin.

In order to achieve a high SPF, formulations generally contain a combination of inorganic and organic ingredients.

- In an attempt to inform the consumers, the level of UV-A protection in sunscreens, the US Food and Drug Administration (US FDA) is proposing a four-star rating system to be displayed near the SPF rating on the label. According to this system, one star will represent low UV-A protection and four stars the highest UV-A protection.

Cosmeceuticals

Cosmetics are something superficial to cover a deficiency or defect. The term **cosmeceuticals** is used to describe cosmetics containing ingredients which may affect the structure or any function of the body like pharmaceutical ingredients.

During the late 1980s, *alpha hydroxy acids* (AHAs) became important ingredients in many cosmetic formulations claiming to reduce signs of aging, sun-damaged skin and wrinkles. These work by breaking down and lifting off part of the top layer of dead skin cells in order to get rid of some surface damage and accelerate growth of living cells. The cosmetic industry believed the ingredients to be more than simple cosmetics and hence called them cosmeceuticals.

Some of these products are only available with a doctor's prescription and supervision. They include, among others, Botox (for a more youthful look), Vaniqa (to eliminate unwanted facial hair) and Propecia (for bald men).

Perfumes

Perfumes are alcoholic solutions of organic compounds with pleasant odors (fragrant compounds). Today, a large variety of natural and synthetic compounds are available to create fragrances for perfumes. In creating perfumes, the ingredients are blended based on their molecular size and volatility.

For this reason, the fragrances in perfumes are generally experienced in three different stages referred to as top, middle and base notes. The top notes are the most volatile components and hence experienced immediately after the opening of the package. The middle notes are experienced next followed by the base notes which last longest.

A recent trend has been to develop more intense and long-lasting alternatives to the known fragrant compounds. Such low-volume production means less impact on energy, health and the environment.

Miscellaneous Products

Deodorants

Body odors are reduced or masked by the use of deodorants. Such odors may originate from the conversion of certain compounds (present in the perspiration) to unpleasant odors by bacteria. Thus the effective chemical ingredients in such products are antibacterial agents and perfumes.

Cosmetics

Facial cosmetics such as lipstick and mascara generally contain oils, waxes, pigments and perfumes. Lipstick manufacturers blend various proportions of oils, waxes and emollients (to soothe the skin) to formulate the base for their unique brand. Fragrances, pigments, preservatives, antioxidants and a variety of other ingredients are then added.

In recent years there has been a concern regarding the presence of low levels of lead in certain cosmetics. A recent testing of a number of brands of lipstick by the US FDA (United States Food and Drug Administration) has shown the presence of low levels of lead. According to the US FDA, the levels observed do not pose a safety concern.

Module 7: Drugs and Medications

Organic Chemistry

Overview

Organic chemistry deals with the study of carbon containing compounds and their reactions. Organic molecules are present in living organisms and in many products used in our everyday lives such as foods, household cleaning products, personal care products etc.

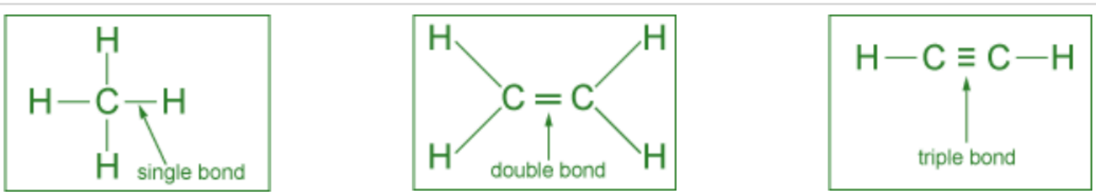
As the element carbon is present in the majority of drugs used today, some basic principles of organic chemistry (the study of carbon compounds) are discussed in this section.

The Element Carbon

The main characteristics of carbon that lead to the formation of such a large number of organic compounds (over 10 million known) with dramatically different physical and chemical properties include the ability to form:

- Covalent single, double and triple bonds with some other elements, including carbon.
- Covalent bonds with other carbon atoms to build chains and cyclic structures.
- Covalent bonds with elements such as hydrogen, nitrogen, oxygen and halogens.

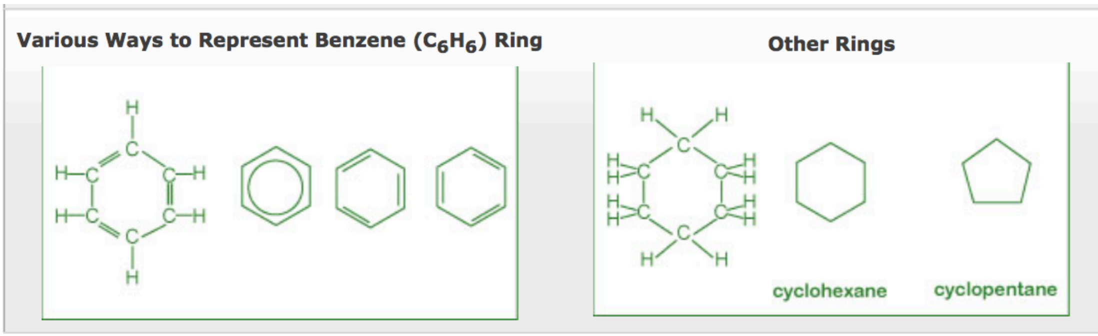
In the structures shown below, each line (bond) represents a pair of electrons.



Single bond: formed by the sharing of one pair of electrons. **Double bond:** formed by the sharing of two pairs of electrons. **Triple bond:** formed by the sharing of three pairs of electrons.

Arrangement of Atoms

Among the cyclic structures, the arrangement of carbon atoms in 5- or 6-membered rings is quite common. The hexagonal (6-membered) ring with three single and three double bonds is called a benzene ring.



Functional Groups

Organic compounds are divided into some important families based on their characteristic functional group. A functional group can be visualized as a small structural unit or arrangement of atoms in a molecule that is the chemically functioning part of the molecule.

In the case of drugs, the functional group(s) are responsible for their action. In addition, the functional group(s) may also determine important parameters such as the rate of uptake and reaction as well as the time of the residence of the drug in the body.

Functional Group	General Formula*	Example
Alcohol	R-OH	Ethyl alcohol: CH_3CH_2OH
Aldehyde	R-CHO	Acetaldehyde: CH_3CHO
Amine	$R\text{-}NH_2$	Methyl amine: CH_3NH_2
Carboxylic Acid	R-COOH	Acetic acid: CH_3COOH
Ester	$R\text{-}COO\text{-}R^1$	Ethyl acetate: $CH_3COOCH_2CH_3$
Ether	$R\text{-}O\text{-}R^1$	Dimethyl ether: CH_3OCH_3
Ketone	$R\text{-}CO\text{-}R^1$	Acetone: CH_5COCH_3

* R and R^1 represent hydrocarbon fragments which can be the same or different

Infections and Diseases

Extensive research with the available sophistication in the field of medicine has led us to engineer molecules that can be used to improve the quality of life by preventing, moderating or curing illnesses.

Antibiotics

Antibiotic drugs are used to fight (prevention of treatment) bacteria that cause infectious diseases such as meningitis, pneumonia, tuberculosis, and so on.

Several different categories of antibiotics include:

- Penicillins
- Cephalosporins
- Tetracyclines

The discovery of a large number of chemically modified derivatives of these antibiotics led to the control of a large variety of bacterial infections. Antibiotics are isolated from bacterial sources, but can also be human-made. Antibiotics act directly on bacteria and destroy them or inhibit their growth. Antibiotics will not kill viruses.

How do antibacterial drugs work?

The actual mechanism of antibacterial drugs is to alter or inhibit one of the following cellular structures/processes:

- Cell wall synthesis - prevents new bacterial cells from forming by preventing formation of the cell wall.
- Cell membrane permeability - kills bacteria cells by causing breakdown of the outer cell membrane.
- Protein synthesis - prevents the bacteria from converting proteins to energy, causing starvation and ultimate cell death.
- Nucleic acid synthesis - keeps bacteria cells from growing by interrupting DNA synthesis.
- Competitive inhibitor - mimics bacteria's growth factors, thus preventing spreading of the bacteria.

Penicillins, Cephalosporins and Tetracyclines

Penicillins

- Treat infections cause by bacteria.
- Do not fight infections caused by viruses.
- Mode of action: affect the development (damaging) of bacterial cell walls.

Cephalosporins

- Cephalosporins have the structure similar to that of penicillins.
- Treat a much broader range of infections compared to penicillins.
- Mode of action: Affect the development of bacterial cell walls.

Tetracyclines

- Chemical structure consisting of four rings.
- Used to treat penicillin-resistant infections.
- Mode of action: Inhibit the synthesis of required bacterial proteins.

Antibiotics vs. Superbugs

The emerging concern in the use of antibiotics is the resistance many of the so-called superbugs have shown towards the known antibiotics. The suggested ways to decrease antibiotic resistance include:

- More cautious use of antibiotics
- Monitoring outbreaks of antibiotic resistances
- Developing new antibiotics

Antiviral Drugs

Antiviral drugs are used to treat (cure or control) viral infections such as flu, polio, herpes and AIDS (Acquired Immune Deficiency Syndrome). A different strategy has to be used to combat viruses, as these do not respond to antibiotics. Two commonly used strategies to fight viral infections include:

Prevention Through Vaccination

When a vaccine (consisting of inactivated virus) is injected, antibodies to fight off a virus are developed and stored in the body. The stored antibodies become available to fight future infection.

Use of Antiviral Drugs

Commonly used antiviral drugs (particularly for the treatment of the AIDS virus) fall into three classes:

- *Nucleoside derivatives* inhibit the synthesis of viral DNA, thus preventing the virus from spreading.
- *Protease inhibitors*, on the other hand, interfere with the viral protein formation, thus preventing their reproduction.
- *A three-drug cocktail* consisting of different nucleoside derivatives and protease inhibitors has shown considerable promise in the treatment of AIDS. This triple cocktail treatment is also known as Highly Active Antiretroviral Therapy (HAART). The success of the therapy is probably due to the cocktail's ability to disrupt the viral replication at different stages. It is important to note that the therapy is very expensive and patients must adhere to their dosing schedule.

Some major problems associated with multiple drug therapy are: moderate effectiveness, lack of response in some cases, serious to severe side effects and drug resistance by the virus. Recent efforts in the fight against AIDS have been directed towards the development of: Viral entry inhibitors (i.e., the drugs that will prevent HIV from attaching and consequently entering into the cell) and Vaccines.

Anticancer Drugs

Cancer involves an uncontrolled division of some cells of the body due to mutation of DNA within the healthy cells. These cells invade nearby tissue and spread throughout the body via the bloodstream or lymphatic system. Thus the chemical treatment of cancer (chemotherapy) involves drugs targeting rapidly dividing cells to kill the cancerous cells.

Alkylating Agents

- Mode of action: due to their high reactivity, alkylating agents introduce defects in the DNA, thus killing the rapidly growing cells by preventing cell growth and multiplication.
- Alkylating agent drugs also effect the growth of normal cells and cause mutations.

Antimetabolites

- Metabolite is a general term for the organic compounds that are synthesized, recycled, or broken down in cells.
- Antimetabolites inhibit DNA synthesis, thus stopping cell replication.
- Mode of action: compete for binding sites on enzymes and are incorporated into nucleic acids.

Topoisomerase Inhibitors

- Topoisomerase inhibitors damage DNA which causes cell death.
- Mode of action: act against the topoisomerase enzymes to prevent cancer cell growth.

Hormone Therapy

- Hormone therapy is used against certain cancers that depend on hormones for their growth. This therapy is used primarily for the treatment of breast cancer and that of the sexual organs. As these tissues require hormones for their growth, the chemotherapeutic agent acts by inhibiting the hormone supply thus stopping the tissue growth.
- Mode of action: stop the production of certain hormones or change their mode of function.

Antidepressants

A deficiency of certain neurotransmitters (any chemical that carries impulses between nerve cells), particularly serotonin in the brain, seems to be partly responsible for causing clinical depression. Neurotransmitters are needed for normal brain function and mood control, in addition to other functions.

Although the effects of antidepressants are not fully understood, there is substantial evidence to show that antidepressants help to restore the brain's chemical balance.

Commonly used antidepressants include:

- Selective Serotonin Reuptake Inhibitors (SSRIs) (e.g. Prozac, Paxil and Zoloft)
- Monoamine Oxidase Inhibitors (MAOIs) (e.g. Nardil, Marplan and Parnate)
- Serotonin and Norepinephrine Reuptake Inhibitors (e.g. Effexor)
- Norepinephrine and Dopamine Reuptake Inhibitors (e.g. Welbutrin)
- Tricyclics (e.g. Norpramine, Pamelor and Tofranil)

Whereas SSRIs target the serotonin levels only, tricyclics affect the brain levels of other neurotransmitters (including serotonin) as well.

Anti-Inflammatory Drugs

Inflammation is the first response of the immune system to infection or irritation characterized by pain, swelling, redness and heat. An inflammation results from the rapid transport of blood proteins and other substances to a damaged tissue site or an area under attack by a foreign organism.

Certain steroids are used as potent anti-inflammatory drugs. These suppress the inflammatory responses of the body, thus reducing inflammation.

Over the Counter Drugs

Whereas all types of drugs discussed earlier require a prescription, a considerable number of drugs are sold OTC without a prescription.

According to the Non Prescription Drug Manufacturers Association, in the US alone there are more than six hundred OTC drugs.

OTC Drug criteria

The criteria generally used by the regulatory agencies to designate a drug with OTC status or switch its status from Rx-to-OTC (i.e., from a prescription drug to one sold without a prescription) involves a benefit-risk comparison and making sure that patients alone can achieve the desired medical result without endangering their safety.

Although OTC drugs allow patients to participate in their own health care, experts emphasize that the labels must be followed closely because OTC drugs are not without risk.

Aspirin - The Best Known OTC Drug

Aspirin, was introduced more than a century ago. It has long been used as an:

- Analgesic (relieving minor pain)
- Antipyretic (lowering fever)
- Anti-inflammatory (reducing swelling) drug

Recent studies have shown its usefulness in treating heart attack and stroke.

Aspirin - Effectiveness and Side Effects

It is believed that Aspiring's effectiveness as an analgesic, anti-inflammatory agent and its protective effects against heart attacks and strokes are due to its inability to reduce the production of prostaglandins (a hormone-like substance that promotes inflammation, fever and pain) and thromboxanes (responsible for platelet aggregation in the formation of blood clots) in the body.

Some possible side effects of Aspirin include:

- Stomach irritation
- Ringing in the ears
- Allergy
- Reye syndrome (brain disorder) in children

Drug Delivery Systems

Active pharmaceutical ingredient (API) in a medicine is delivered to the body in many forms, such as tablets, gelcaps, liquids and so on. Some newer alternate methods for drug delivery have three major advantages:

- User convenience
- Improved drug performance
- Better patient compliance

Some of these methods include:

- Pulmonary delivery: The system is noninvasive and facilitates the rapid absorption of the drug on the large surface area of the lungs followed by rapid desorption into the bloodstream.
- Skin absorption: Skin patches are being used to deliver the medication via skin absorption.
- Nanocrystals: This method reduces the drug particle size to nanoscale (<400 nm) making it more soluble in body fluids.

Effects & Trends

Environmental Effects of Pharmaceuticals

Recent research has led scientists to be concerned about the environmental impact of old and/or expired medications that are discarded. The pharmaceuticals enter the environment mostly through raw or treated sewage.

Some of the effects observed include:

- Feminization of male fish due to estrogenic compounds: The signs of feminization in male fish have been concluded as a response to estrogen (in birth control pills) exposure.
- Slow development of fish and frogs due to certain antidepressants: Profound effects on spawning and other behaviours in shellfish can occur with antidepressants such as Selective Serotonin Reuptake Inhibitors (SSRIs).

Recent Trends in Pharmaceutical Development

In the field of pharmaceutical development, the present trends include:

- A shift from blockbuster drugs (drugs that work for a large number of patients) to personalized medicine: In personalized medicine, therapies are catered towards genetic profiles of patients and their diseased cells.
- Exploring marine organisms in an attempt to obtain new compounds with therapeutic potential: Several of these compounds are being investigated as potential anticancer agents, analgesics and anti-inflammatory drugs.

Medications & Health

Drugs should not be considered risk-free chemical substances. It is strongly recommended by health professionals that patients should always bear in mind the fact that medications have side effects and may have serious interactions with other medications, dietary supplements, food and beverages consumed.

In order to reduce risks, it is strongly recommended that all individuals:

- Read drug labels carefully.
- Learn about the warnings of all drugs taken.
- Inform health care providers of all prescription and OTC drugs and dietary supplements taken.
- Keep a record of all medications taken.

Module 8: Some Environmental Concerns

Acid Rain

How Does This Happen?

When atmospheric carbon dioxide dissolves in water it forms carbonic acid.

$$CO_2\ (g) + H_2O\ (\ell) \rightarrow H_2CO_3\ (aq)$$

The acid formed dissociates partially generating small amounts of hydrogen ions.

$$H_2CO_3\ (aq) \rightarrow H^+\ (aq) + HCO_3^-\ (aq)$$

The hydrogen ions formed are responsible for the weakly acidic nature of rain.

The pH Scale

The acidity (a measure of hydrogen ion concentration) of a solution is conveniently described in terms of pH scale.

According to this scale, if:
- $pH < 7$: solution is acidic
- $pH > 7$: solution is basic
- $pH = 7$: solution is neutral

↑ Acidity = ↓ pH

Based on the concentration of carbonic acid and small amounts of other natural acids, the estimated pH of rain (as well as fog, dew and snow) under normal atmospheric conditions should be around 5.3. Field measurements in many areas, on the other hand, show much lower pH values (4.1- 4.5). Higher acidity (lower pH) is due to the reactions of NO_x and SO_x present in the atmosphere.

Various reactions of these oxides lead to the formation of acids. The dissociation of formed acids generates hydrogen ions and hence higher acidity (or lower pH).

$2\ SO_2\ (g) + O_2\ (g) + 2\ H_2O\ (\ell) \rightarrow 2\ H_2SO_4\ (aq)$
$H_2SO_4\ (aq) \rightarrow H^+\ (aq) + HSO_4^-\ (aq)$
$HSO_4^-\ (aq) \rightarrow H^+\ (aq) + SO_4^{2-}\ (aq)$
$4\ NO_2\ (g) + O_2\ (g) + 2\ H_2O\ (\ell) \rightarrow 4\ HNO_3\ (aq)$
$HNO_3\ (aq) \rightarrow H^+\ (aq) + NO_3^-\ (aq)$

Environmental Effects

Material Damage

Marble and limestone ($CaCO_3$) used in many historic and irreplaceable statues and buildings (e.g., the Parthenon in Greece, the Taj Mahal in India) react with acid in the rain.

The reaction leads the formation of calcium salts. The solubility of these salts in water is much greater than that of marble in water. The dissolution of formed calcium salts leads to roughened surfaces, removal of material and loss of carved details from the buildings and statues.

$$CaCO_3\ (s) + 2\ H^+\ (aq) \rightarrow Ca^{2+}\ (aq) + CO_2\ (g) + H_2O\ (\ell)$$

Forest Damage

Considerable damage to trees has been reported in various parts of North America and Europe. Acid rain has been implicated with slower growth, injury and destruction of forests and has been attributed to be a contributing factor to the declining health of trees by damaging their leaves, limiting the nutrients available to them or exposing them to toxic substances released from the soil due to the change in pH.

Acid rain is implicated in depleting the nutrient supply to the trees by:

- Attacking the leaves whose protective coating has already been destroyed due to attack by other atmospheric pollutants such as O3 and NOx.
- Mobilizing various metals (Al, Pb, etc.) in the soil that attack the roots.

Inadequate nutrient supply increases the possibility of destruction due to disease, drought, insects or high winds.

Corrosion of Metals

The corrosion process is accelerated in the presence of acid. Thus, iron structures, bridges, railroads, etc. show a faster rate of corrosion (rusting) in acid rain predominant areas. Studies indicated that even painted or plated iron corrodes more rapidly in such areas.

The reaction occurs in two steps with hydrogen ions (formed from the dissociation of acid) being involved in the first step of the reaction. The overall reaction, conversion of iron to its oxide (rust), can be represented as follows:

$$4\ Fe\ (s) + 3\ O_2\ (g) \rightarrow 2\ Fe_2O_3\ (s)$$

Aquatic Life

Aquatic life is quite susceptible to changes in pH. Reduced pH has led to lakes with no fish or other living beings. Acid rain has been shown to reduce fish population, kill individual fish and in some cases eliminate fish species entirely from a body of water.

Adverse effects of acid rain in aquatic life are due to:

- Lowering of pH well below the required value of about 6.5 for healthy aquatic life.
- Increasing aqueous concentration of metals (Al,Pb, etc.) due to their higher solubility at lowered pH.

Both low pH and increased aluminum levels are directly toxic to fish. In addition, low pH and increased aluminum levels cause chronic stress leading to smaller size and lower body weight. These factors in turn make the fish less able to compete for food and habitat.

Control Strategies

Reduction of SOx emissions by using emission control technologies:

Over the years, progress has been made in reducing the emissions of sulfur dioxide. The major strategies under consideration include:

- Using coal with low sulfur content
- Removing sulfur from the coal before using
- Using chemicals to neutralize acidic sulfur dioxide

In view of the substantial cost involved in using any of the above strategies individually or in combination, the progress in this direction has been rather slow in North America. In Japan, using the above technologies in particular the use of scrubbers (for the neutralization of acidic sulfur dioxide) has led to considerable decrease in sulfur dioxide emissions.

Reduction of NOx emissions by using emission control technologies:

Catalytic converters are now in use in automobiles to reduce the emission of oxides of nitrogen.

Using cleaner energy sources in transportation:

These cleaner energy sources (such as alcohol and hydrogen) are being explored. A number of projects all over the globe are in progress. In some parts of the US there is limited use of alcohol to replaces gasoline in cars. There are considerable numbers of investigations in progress pertaining to the use of hydrogen as fuel.

Developing and/or using alternate energy (i.e., hydroelectric, nuclear or wind) sources":

Hydroelectric, nuclear and wind power are being used in many parts of the world. However, the progress in their development is very slow primarily due to high initial costs and environmental issues.

Global Warming

How Does This Happen?

Global warming refers to an increase in the Earth's average temperature. This warming is the result of increased absorption by the atmosphere of infrared (IR), a major source of heat, radiated back from Earth's surface. This is due to an increase in concentration of gases that trap heat in the atmosphere. These gases are often called greenhouse gases.

The principal greenhouse gases that enter the atmosphere due to human activities include:

Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)	Fluorinated gases
It enters the atmosphere due to the burning of fossil fuels (oil, natural gas, and coal), waste materials, and as a result of other chemical reactions.	Main sources of emission are the production and transport of fossil fuels, livestock, agricultural practices and organic waste decay.	It is emitted during agricultural and industrial activities as well as during the combustion of fossil fuels and waste materials.	These fluorine containing compounds are emitted from a variety of industrial processes and are sometimes called High Global Warming Potential (GWP) gases.

Based on measured concentrations of various greenhouse gases, computer models have been developed to predict the extent of global warming. It is estimated that the temperature of the atmosphere may increase anywhere from 1.5°C to 3.5°C during the next fifty years.

Environmental Effects

Climatic changes:

Human activities such as burning of fossil fuels, deforestation, industrial processes and some agricultural practices release greenhouse gases. These gases trap energy in the atmosphere causing it to warm.

Changes in sea level due to melting of polar ice caps:

The North Pole is warming up faster than the rest of the world. The Arctic sea ice is in a state of ongoing decline as shown by the data from the National Snow and Ice Data Center (NSIDC) in the US.

Possibility of droughts and increased frequency of heat waves due to warming:

Based upon detailed analysis using computer climate models and other relevant data, it is concluded that in the next few decades increasingly dry conditions may be encountered across much of the globe.

Changes in ecosystem:

As many animals and plants survive within a narrow range of climatic conditions, some animal species are shifting towards higher elevations. Many species even face extinction. As ocean temperatures rise, the coral reefs will continue to decline.

Effects on Human Health:

Global warming may lead to increased temperature-related illnesses, air pollution due to higher temperatures, and possible spread of some infectious diseases.

Control Strategies

Some of the suggested control strategies include:

Reduction in CO_2 emissions: The governments all over the globe are working to reduce their country's carbon dioxide emissions by:

- Promoting that alternate non-fossil sources such as hydroelectric, solar, nuclear and wind are developed and used
- Capturing the carbon dioxide generated by burning fossil fuels
- Supporting new fuels and technologies (like electric cars) to reduce carbon dioxide emissions from transport
- Setting 'carbon budgets' to cap overall carbon dioxide emissions.

Encouraging energy conservation: This will lead to lesser energy consumption and hence lower production and reduced emissions.

Using carbon dioxide sinks: A carbon dioxide sink is any resource (natural or artificial) that captures and stores atmospheric carbon dioxide. Natural carbon dioxide sinks include forests, oceans and soil. Thus replanting forests is being encouraged globally.

Some of the artificial carbon dioxide sinks being studied involve removing carbon dioxide from the atmosphere and storing it in rocks, injecting it deep into the oceans or trapping it via chemical reactions.

Present Situation

Key Events to limit Global Warming

1988 - Intergovernmental Panel on Climate Change.

In 1988, United Nations Environment Program (UNEP) and World Meteorological Organization established Intergovernmental Panel on Climate Change (IPCC) to focus on:

- Assessment of scientific knowledge
- Examination of the environmental, economic and social impacts
- Formulation of response strategies

2007 - Intergovernmental Panel on Climate Change.

A report released by the Intergovernmental Panel on Climate Change (IPCC) in 2007 stated that global warming is clearly evident from diverse observations such as:

- Increases in average air and ocean temperatures
- Widespread melting of snow and ice
- Rising global average sea level

The report emphasizes that global warming could cause irreversible damage to the planet. It is concluded and strongly suggested by scientists that global, sweeping, concerted action is urgently needed to drastically reduce greenhouse gas emissions. In addition, a report on the global economic impact of global warming (the Stern Report) suggests that it could shrink the global economy by 20%

1997 - Kyoto protocol

In order to limit global warming (due to the trapping of heat in the atmosphere by greenhouse gases), the Kyoto protocol was signed in 1997. The document calls for industrialized nations to cut their emissions of greenhouse gases.

Summary

However, the progress in the implementation of diverse measures to control the emission of greenhouse gases and thereby limit the extent of global warming is going to be slow. The reason for this is the present situation of the global economy and hence the reluctance of governments to implement tighter environmental controls on emissions.

Ozone Depletion

How Does This Happen?

Ozone plays a double role in our environment:

- In our immediate atmosphere, it acts as an air pollutant contributing to photochemical smog
- In the stratosphere (in conjunction with oxygen), it filters the solar ultraviolet (UV) radiation, thus protecting us against its harmful effects

In our immediate atmosphere exposure to ozone may occur in operations involving:

- High-intensity UV light such as mercury vapor lamps, plasma torches, glass blowing, etc.
- High-voltage electrical equipment
- Welding

In all the above operations, the interaction of high energy with oxygen in the surrounding atmosphere leads to the formation of O_3:

$$3\ O_2\ (g) + \text{Energy} \rightarrow 2\ O_3\ (g)$$

Ozone Formation

In the stratosphere, oxygen and ozone interact with energy (ultraviolet radiation) from solar radiation to form a dynamic system involving the following reactions:

When ultraviolet light strikes oxygen molecule, individual oxygen atoms are produced.	$O_2 + \text{Energy} \rightarrow 2\ O$
The combination of atomic oxygen with oxygen molecule leads to the formation of ozone.	$O_2 + O \rightarrow O_3$
The interaction of ozone molecule with ultraviolet light splits it into a molecule of oxygen and an atom of oxygen.	$O_3 + \text{Energy} \rightarrow O_2 + O$
Recombination of ozone molecule with an oxygen atom leads to the formation of oxygen molecule.	$O_3 + O \rightarrow 2\ O_2$

The above processes occur repeatedly and are together called ozone-oxygen cycle or Chapman cycle. This constitutes the O_2/O_3 screen that filters out the ultraviolet component of the solar radiation.

Environmental Concern

The environmental concern in the case of ozone is its stratospheric depletion, which leads to less efficient filtration of harmful solar UV rays. The depletion is caused by both natural (water vapor, nitric oxide) as well as human-made (chlorofluorocarbons, halons) sources.

These manufactured chemicals, containing chlorine and/or bromine are called "ozone-depleting substances" (ODS). The use and popularity of these chemicals is due to their stability and low toxicity.

Chloroflurocarbons (CFCs) and halons have been used as:

- Foam-blowing agents
- Solvents
- Fire-extinguishing agents
- Refrigerants

However, their stability and long lifetime (up to several centuries) allows them to reach the stratosphere. The interaction of these molecules with ultraviolet light in the stratosphere leads to the generation of chlorine and bromine which in turn destroy stratospheric ozone.

Effects of Depletion

Stratospheric ozone depletion leading to less efficient filtration of the ultraviolet radiation from the sun, will incase the intensity of ground-level UV radiation. The increases intensity may have adverse effects on:

Humans

Such adverse effects include:

- Higher probability of sunburns, skin cancer and premature aging of skin
- More cataracts, eye diseases and blindness
- Immunosuppression (weakening of the human immune system)

Agriculture and Forestry

Physiological and developmental processes of major crop species (such as barley, rice and wheat) may be affected. The data available on the effect of more intense ultraviolet radiation on commercially important trees shows that plant growth is harmed.

Materials

Increased intensity of ultraviolet radiation may accelerate the degradation of materials such as fabrics, plastics, rubber and wood.

Marine Ecosystems

Increased intensity of ultraviolet radiation may:

- Damage marine life by decreasing the plankton. Such a decrease in plankton could disrupt the food chains leading to a shift in marine species in global waters
- Lead to decreased reproductive capacity reduce fish yields.

Control Strategies

In North America, the use of chlorofluorocarbons (as propellants in spray cans) was banned in 1978 in response to the threat of ozone depletion. The global response to the threat of ozone depletion came with the signing of the Montreal Protocol (in 1987). It set out to reduce and ultimately ban the manufacture and use of CFCs and other ozone depleting substances.

The international agreement has been effective in reducing risks in the long term; ultraviolet radiation remains a health hazard. In view of this, we as individuals should protect ourselves against it.