

The Islamic University of Gaza- Environmental Engineering Department  
Environmental Chemistry I (EENV 2301)

**CHAPTER 5: WATER POLLUTION**

Nature and Types of Water Pollutants  
Elemental Pollutants, Heavy Metal, Metalloid  
Organically Bound Metals and Metalloids  
Inorganic Species  
Oxygen, Oxidants, and Reductants  
Organic Pollutants, Pesticides in Water and Polychlorinated Biphenyls  
Radioactive pollution

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## General Types of Water Pollutants

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Class of pollutant	Significance
Trace Elements	Health, aquatic biota, toxicity
Heavy metals	Health, aquatic biota, toxicity
Organically bound metals	Metal transport
Radionuclides	Toxicity
Inorganic pollutants	Toxicity, aquatic biota
Asbestos	Human health
Algal nutrients	Eutrophication
Acidity, alkalinity, salinity (in excess)	Water quality, aquatic life
Trace organic pollutants	Toxicity
Polychlorinated biphenyls	Possible biological effects
Pesticides	Toxicity, aquatic biota, wildlife
Petroleum wastes	Effect on wildlife, esthetics
Sewage, human and animal wastes	Water quality, oxygen levels
Biochemical oxygen demand	Water quality, oxygen levels
Pathogens	Health effects
Detergents	Eutrophication, wildlife, esthetics
Chemical carcinogens	Incidence of cancer
Sediments	Water quality, aquatic biota, wildlife
Taste, odor, and color	Esthetics

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## Important Trace Elements in Natural Waters

Element	Sources	Effects and Significance
Arsenic	Mining byproduct, chemical waste	Toxic <sup>1</sup> , possibly carcinogenic
Beryllium	Coal, industrial wastes	Toxic
Boron	Coal, detergents, wastes	Toxic
Chromium	Metal plating	Essential as Cr(III), toxic as Cr(VI)
Copper	Metal plating, mining, industrial waste	Essential trace element, toxic to plants and algae at higher levels
Fluorine (F <sup>-</sup> )	Natural geological sources, wastes, water additive	Prevents tooth decay at around 1 mg/L, toxic at higher levels
Iodine (I <sup>-</sup> )	Industrial wastes, natural brines, seawater intrusion	Prevents goiter
Iron	Industrial wastes, corrosion, acid mine water, microbial action	Essential nutrient, damages fixtures by staining
Lead	Industrial waste, mining, fuels	Toxic, harmful to wildlife
Manganese	Industrial wastes, acid mine water, microbial action	Toxic to plants, damages fixtures by staining
Mercury	Industrial waste, mining, coal	Toxic, mobilized as methyl mercury compounds by anaerobic bacteria
Molybdenum	Industrial wastes, natural sources	Essential to plants, toxic to animals
Selenium	Natural sources, coal	Essential at lower levels, toxic at higher levels
Zinc	Industrial waste, metal plating, plumbing	Essential element, toxic to plants at higher levels

# Guidelines for Drinking-water Quality

THIRD EDITION  
INCORPORATING THE FIRST AND SECOND  
ADDENDA  
Volume 1  
**Recommendations**



World Health  
Organization

Geneva  
2008

**Chemical Standards**  
**(Compounds affecting health and water suitability)**

<b>Element/Compound</b>	<b>Symbol</b>	<b>Acceptable Level (mg/l)</b>	<b>MCL (mg/l)</b>
<b>Total Dissolved Solids</b>	<b>TDS</b>	<b>500</b>	<b>1500</b>
<b>Total Hardness</b>	<b>TH (CaCO<sub>3</sub>)</b>	<b>100</b>	<b>500</b>
<b>Detergents</b>	<b>ABS</b>	<b>0.5</b>	<b>1</b>
<b>Aluminum</b>	<b>Al</b>	<b>0.2</b>	<b>0.3</b>
<b>Iron</b>	<b>Fe</b>	<b>0.3</b>	<b>1</b>
<b>Manganese</b>	<b>Mn</b>	<b>0.1</b>	<b>0.2</b>
<b>Copper</b>	<b>Cu</b>	<b>1</b>	<b>1.5</b>
<b>Zinc</b>	<b>Zn</b>	<b>5</b>	<b>15</b>
<b>Sodium</b>	<b>Na</b>	<b>200</b>	<b>400</b>
<b>Nickel</b>	<b>Ni</b>	<b>0.05</b>	<b>0.1</b>
<b>Chloride</b>	<b>Cl</b>	<b>200</b>	<b>400</b>
<b>Fluoride</b>	<b>F</b>	<b>1</b>	<b>1.5</b>
<b>Sulfate</b>	<b>SO<sub>4</sub></b>	<b>200</b>	<b>500</b>
<b>Nitrate</b>	<b>NO<sub>3</sub></b>	<b>45</b>	<b>70</b>
<b>Silver</b>	<b>Ag</b>	<b>0.01</b>	<b>0.05</b>
<b>Magnesium</b>	<b>Mg</b>	<b>50</b>	<b>120</b>
<b>Calcium</b>	<b>Ca</b>	<b>100</b>	<b>200</b>
<b>Potassium</b>	<b>K</b>	<b>10</b>	<b>12</b>

## Chemical Standards (Toxic elements)

Parameter	Symbol	MCL (mg/l)
Lead	Pb	0.01
Selenium	Se	0.01
Arsenic	As	0.05
Chromium	Cr	0.05
Cyanide	Cn	0.05
Cadmium	Cd	0.005
Mercury	Hg	0.001
Antimony	Sb	0.005
Nickel	Ni	0.05

## Palestinian drinking water quality standards

Element/Compound	Symbol	MCL (mg/l)
Total Dissolves Solids	TDS	1500
Total Hardness	TH (CaCO <sub>3</sub> )	600
Alkalinity		400
Detergents	ABS	0.5
Sodium	Na	200
Chloride	Cl	600
Fluoride	F	1.5
Sulfate	SO <sub>4</sub>	400
Nitrate	NO <sub>3</sub>	70
Nitrite	NO <sub>2</sub>	0.1
Ammonium	NH <sub>4</sub>	0.5
Magnesium	Mg	150
Calcium	Ca	100- 200
Potassium	K	12
Residual chlorine		0.2- 0.8

## ELEMENTAL POLLUTANTS

**Trace element** is a term that refers to those elements that occur at very low levels of a few parts per million or less in a given system.

Some of these are recognized as nutrients required for animal and plant life, including some that are essential at low levels but toxic at higher levels.

Some of these elements, such as **lead or mercury**, have such toxicological and environmental significance.

Some of the **heavy metals** are among the most harmful of the elemental pollutants and are of particular concern because of their toxicities to humans.

These elements are, in general, the transition metals, and some of the representative elements, such as **lead and tin**, in the **lower right-hand corner of the Periodic Table**.

Heavy metals include essential elements like iron as well as toxic metals like **cadmium and mercury**.

Most of them have a tremendous affinity for sulfur, and disrupt enzyme function by forming bonds with sulfur groups in enzymes. Protein carboxylic acid ( $-\text{CO}_2\text{H}$ ) and amino ( $-\text{NH}_2$ ) groups are also chemically bound by heavy metals. Cadmium, copper, lead, and mercury ions bind to cell membranes, hindering transport processes through the cell wall.



Some of the **metalloids**, elements on the borderline between metals and non- metals, are significant water pollutants. Arsenic, selenium, and antimony are of particular interest.

**Inorganic chemicals** manufacture has the potential to contaminate water with trace elements. Among the industries regulated for potential trace element pollution of water are those producing chloralkali, hydrofluoric acid, sodium dichromate (sulfate process and chloride ilmenite process), aluminum fluoride, chrome pigments, copper sulfate, nickel sulfate, sodium bisulfate, sodium hydrosulfate, sodium bisulfite, titanium dioxide, and hydrogen cyanide.

## **HEAVY METALS**

**Cadmium:** Pollutant cadmium in water may arise from industrial discharges and mining wastes.

**Chemically, cadmium** is very **similar to zinc**, and these two metals frequently undergo geochemical processes together.

Both metals are found in water in the +2 oxidation state.

**The effects of acute cadmium poisoning in humans are very serious. Among them are high blood pressure, kidney damage, destruction of testicular tissue, and destruction of red blood cells. It is believed that much of the physiological action of cadmium arises from its chemical similarity to zinc. Specifically, cadmium may replace zinc in some enzymes, thereby altering the stereostructure of the enzyme and impairing its catalytic activity.**

**Lead:** Inorganic lead arising from a number of industrial and mining sources occurs in water in the +2 oxidation state.

Lead from leaded gasoline used to be a major source of atmospheric and terrestrial lead, much of which eventually entered natural water systems.

Acute lead poisoning in humans may cause severe dysfunction of the kidney, reproductive system, liver, brain, and central nervous system leading to sickness or death.

Lead poisoning from environmental exposure is thought to have caused mental retardation in many children.

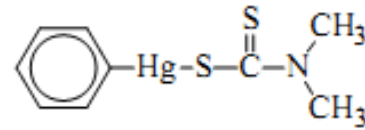
Mild lead poisoning causes anemia. The victim may have headaches and sore muscles, and may feel generally fatigued and irritable.

**Mercury:** generates a great deal of concern as a heavy metal pollutant. Mercury is found as a trace component of many minerals, with continental rocks containing an average of around 80 parts per billion, or slightly less.

Fossil fuel coal and lignite contain mercury, often at levels of 100 parts per billion or even higher, a matter of some concern with increased use of these fuels for energy resources.

Metallic mercury is used as an electrode in the electrolytic generation of chlorine gas, in laboratory vacuum apparatus, and in other applications.

Organic mercury compounds used to be widely applied as pesticides, particularly fungicides. These mercury compounds include aryl mercurials such as phenyl mercuric dimethyl- dithiocarbamate



Mercury enters the environment from discarded laboratory chemicals, batteries, broken thermometers, amalgam tooth fillings, and formerly lawn fungi- cides and pharmaceutical products.

Taken individually, each of these sources may not contribute much of the toxic metal, but the total effect can be substantial. Sewage effluent sometimes contains up to 10 times the level of mercury found in typical natural waters.

The toxicity of mercury was tragically illustrated in the Minamata Bay area of Japan during the period 1953–1960. A total of 111 cases of mercury poisoning and 43 deaths were reported among people who had consumed seafood from the bay that had been contaminated with mercury waste from a chemical plant that drained into Minamata Bay. Congenital defects were observed in 19 babies whose mothers had consumed seafood contaminated with mercury. The level of metal in the contaminated seafood was 5–20 parts per million.

Among the toxicological effects of mercury are neurological damage, including, irritability الهيجان paralysis, blindness, or insanity جنون; chromosome breakage; and birth defects.

## METALLOIDS

The most significant water pollutant metalloid element is arsenic.

**Acute arsenic poisoning** can result from the ingestion of more than about **100 mg** of the element

Chronic poisoning occurs with the ingestion of small amounts of arsenic over a long period of time. There is some evidence that this element is also **carcinogenic**.

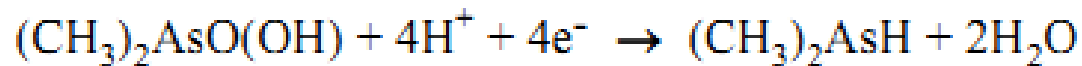
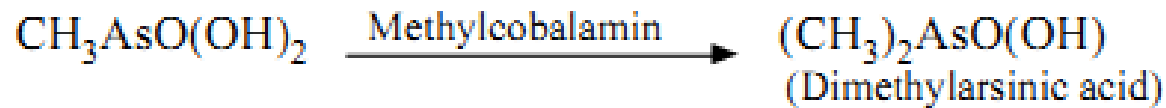
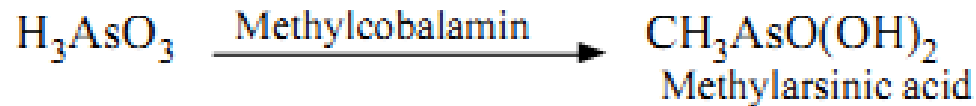
Arsenic occurs in the Earth's crust at an average level of 2–5 ppm. The combustion of fossil fuels, particularly coal, introduces large quantities of arsenic into the environment, much of it reaching natural waters.

Arsenic occurs with phosphate minerals and enters into the environment along with some phosphorus compounds.

Some formerly used pesticides, particularly those from before World War II, contain highly toxic arsenic compounds. The most common of these are lead arsenate,  $\text{Pb}_3(\text{AsO}_4)_2$ ; sodium arsenite,  $\text{Na}_3\text{AsO}_3$ ; and Paris Green,  $\text{Cu}_3(\text{AsO}_3)_2$ .

Another major source of arsenic is mine tailings. Arsenic produced as a by-product of copper, gold, and lead.

Arsenic can be converted by bacteria to more mobile and toxic methyl derivatives according to the following reactions:



## Effects of Exceeding MCL

**Aluminium (Al):** Related to Alzheimer's (فقد الذاكرة)

**Arsenic (As):** Accumulate in the body. Carcinogenic

**Cadmium (Cd):** Accumulate in the body. Highly toxic. adverse changes in arteries الشرايين of human kidneys. linked with certain human cancers

**Calcium (Ca)** form harmful scales in boilers, pipes, and cooking utensils أواني الطبخ.  $\text{CaCO}_3$  contributes to the total hardness of water

**Iron (Fe):** cause staining of laundry and porcelain bittersweet taste is detected at levels above 1 mg/l

**Magnesium (Mg)** Important contributors to the water hardness forming scales in boiler. have a cathartic مسهل and diuretic مدر للبول effect Manganese (Mn): cause objectionable stains to laundry

**Mercury (Hg):** Accumulate in the food chain very toxic and not allowed to exist in the environment or water

**Selenium (Se):** toxic to animals and may be toxic to humans

**Silver (Ag)** cause argyria, a permanent blue-gray discoloration of the skin and eyes that causes a ghostly appearance pathological changes in the kidneys, liver, and spleen الطحال of rats. Toxic effects on fish in fresh water have been observed at conc. as low as 0.17 ug/l

**Sodium (Na)** : Ratio of sodium to total cations (SAR) is important in agriculture and human pathology. Soil permeability may be harmed by a high sodium ratio.

Persons afflicted with certain diseases require water with low sodium concentration

**Vanadium (V)**: It plays a beneficial role in the prevention of heart disease. In New Mexico, with low heart disease cases, water contained 20-150 ug/l.

In a state where heart disease is high, water did not contain vanadium. Vanadium pentoxide dust causes gastrointestinal and respiratory disturbances.

**Zinc (Zn)**: It is essential and beneficial element in plant and animal growth. Concentrations above 5 mg/l can cause bitter taste and an opalescence تَلَأُو in alkaline waters.

**Chloride (Cl<sup>-</sup>)**: High conc. of Cl<sup>-</sup> may harm: metallic pipes and structures and growing plants.

**Cyanide CN<sup>-</sup>**: Highly toxic.

**Fluoride F<sup>-</sup>**: Fluorosis

**Nitrate NO<sub>3</sub>**: Blue baby syndrome (methemoglobinemia)

**Sulfate SO<sub>4</sub>**: Na<sub>2</sub>(SO<sub>4</sub>) and MgSO<sub>4</sub> have cathartic effects مسهل

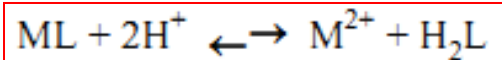
## ORGANICALLY BOUND METALS AND METALLOIDS

The interaction of metals with organic compounds is of utmost importance in determining the role played by the metal in an aquatic system.

There are two major types of metal-organic interactions to be considered in an aquatic system.

The first of these is complexation, usually chelation when organic ligands are involved.

A reasonable definition of complexation by organics applicable to natural water and wastewater systems is a system in which a species is present that reversibly dissociates to a metal ion and an organic complexing species as a function of hydrogen ion concentration



$M^{2+}$  is a metal ion and  $H_2L$  is the acidic form of a complexing-frequently chelating-ligand,  $L^{2-}$ , illustrated here as a compound that has two ionizable hydrogens.

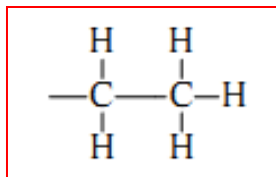
Organometallic compounds, on the other hand, contain metals bound to organic entities by way of a carbon atom and do not dissociate reversibly at lower pH or greater dilution.

Furthermore, the organic component, and sometimes the particular oxidation state of the metal involved, may not be stable apart from the organometallic compound.

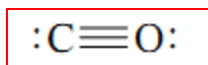


A simple way to classify organometallic compounds for the purpose of discussing their toxicology is the following:

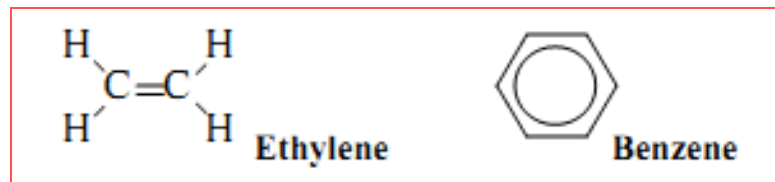
1. Those in which the organic group is an alkyl group such as ethyl tetra-ethyllead,  $\text{Pb}(\text{C}_2\text{H}_5)_4$



2. Carbonyls, some of which are quite volatile and toxic, having carbon monoxide bonded to metals:



3. Those in which the organic group is a p electron donor, such as ethylene or benzene.



## INORGANIC SPECIES

**Cyanide,  $\text{CN}^-$**  a deadly poisonous substance exists in water as HCN, a weak acid,  $K_a = 6 \times 10^{-10}$

The cyanide ion has a strong affinity for many metal ions, forming relatively less-toxic ferrocyanide,  $\text{Fe}(\text{CN})_6^{-4}$  with iron(II).

Volatile HCN is very toxic and has been used in gas chamber executions in the U.S.

Cyanide is widely used in industry, especially for metal cleaning and electro plating

**Ammonia,  $\text{NH}_3$** : is the initial product of the decay of nitrogenous organic wastes, and its presence frequently indicates the presence of such wastes

Natural levels in groundwater and surface water are usually below 0.2 mg/litre. Anaerobic groundwater may contain up to 3mg/litre.

**Hydrogen sulfide,  $\text{H}_2\text{S}$** : is a product of the anaerobic decay of organic matter containing sulfur.

It is also produced in the anaerobic reduction of sulfate by microorganisms and is evolved as a gaseous pollutant from geothermal waters.

Wastes from chemical plants, paper mills, textile mills, and tanneries may also contain  $\text{H}_2\text{S}$ . Its presence is easily detected by its characteristic rotten-egg odor.

**Nitrite ion,  $\text{NO}_2^-$ :** occurs in water as an intermediate oxidation state of nitrogen over a relatively narrow pE range.

Nitrite is added to some industrial process water as a corrosion inhibitor.

However, it rarely occurs in drinking water at levels over 0.1 mg/L.

**Sulfite ion,  $\text{SO}_3^{2-}$ :** is found in some industrial wastewaters.

Sodium sulfite is commonly added to boiler feed-waters as an oxygen scavenger where it reacts to remove potentially corrosive dissolved molecular oxygen from the water:

## **Asbestos in Water**

The toxicity of inhaled asbestos is well established.

The fibers scar lung tissue and cancer eventually develops, often 20 or 30 years after exposure.

It is not known for sure whether asbestos is toxic in drinking water.

Asbestos is introduced into water by the dissolution of asbestos-containing minerals and ores as well as from industrial effluents, atmospheric pollution and asbestos-cement pipes in the distribution system.

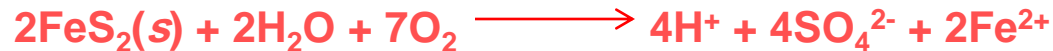
## ACIDITY, ALKALINITY, AND SALINITY

The most common source of **pollutant acid** in water is acid mine drainage.

Acid mine water results from the presence of sulfuric acid produced by the oxidation of pyrite,  $\text{FeS}_2$ .

Microorganisms are closely involved in the overall process, which consists of several reactions.

The first of these reactions is the bacterially mediated oxidation of pyrite:



**Water Salinity:** Water **salinity** may be increased by a number of human activities.

Water passing through a municipal water system surely picks up salt from a number of processes; for example, recharging water softeners with sodium chloride is a major contributor to salinity in municipal wastewater.

Irrigation adds a great deal of salt to water. This occurs when water seeps into a slight depression in tilled, sometimes irrigated, fertilized land, carrying salts (particularly sodium, magnesium, and calcium sulfates) along with it.

In the coastal areas the sea water intrusion is the main source of salts to the groundwater.

## OXYGEN, OXIDANTS, AND REDUCTANTS

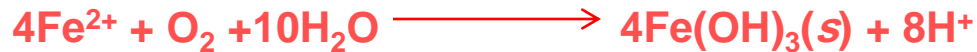
Oxygen is a vitally important species in water. In water, oxygen is consumed rapidly by the oxidation of organic matter,  $\{\text{CH}_2\text{O}\}$ :



Unless the water is re-aerated efficiently, as by turbulent flow in a shallow stream, it rapidly loses oxygen and will not support higher forms of aquatic life. In addition to the microorganism-mediated oxidation of organic matter, oxygen in water may be consumed by the bio-oxidation of nitrogenous material,



and by the chemical or biochemical oxidation of chemical reducing agents:



## ORGANIC POLLUTANTS

**Sewage:** contains a wide variety of pollutants, including organic pollutants. Some of these pollutants, particularly oxygen-demanding substances (oil, grease, and solids) are removed by primary and secondary sewage-treatment processes. Others, such as salts, heavy metals, and refractory (degradation-resistant) organics, are not efficiently removed.

**Biochemical oxygen demand or BOD:** is a procedure for determining the rate of uptake of dissolved oxygen by the organisms in a body of water. BOD measures the oxygen uptake by bacteria in a water sample at a temperature of 20°C over a period of 5 days in the dark.

The sample is diluted with oxygen saturated de-ionized water, measuring the (DO) and then sealing the sample to prevent further oxygen addition.

The sample is kept at 20°C for five days, in the dark to prevent addition of oxygen by photosynthesis, and the dissolved oxygen is measured again.

The difference between the final DO and initial DO is the BOD or, BOD<sub>5</sub>. Once we have a BOD<sub>5</sub> value, it is treated as just a concentration in mg/L

BOD can be calculated by: Diluted: (Initial DO - Final DO) x Dilution Factor

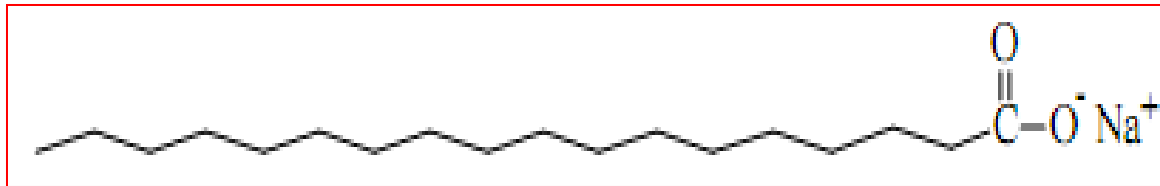
Significance: BOD is a measure of organic content and gives an indication on how much oxygen would be required for microbial degradation.

## Soaps, Detergents

Soaps are salts of higher fatty acids, such as sodium stearate,  $C_{17}H_{35}COO^-Na^+$ .

*Soap's cleaning action results largely from its emulsifying power and its ability to lower the surface tension of water.* This concept can be understood by considering the dual nature of the soap anion.

Its structure shows that the stearate ion consists of an ***ionic carboxyl "head"*** and a long ***hydrocarbon "tail"***.



## Detergents

Synthetic detergents have good cleaning properties and do not form insoluble salts with "hardness ions" such as calcium and magnesium.

Such synthetic detergents have the additional advantage of being the salts of relatively strong acids and, therefore, they do not precipitate out of acidic waters as insoluble acids, an undesirable characteristic of soaps.

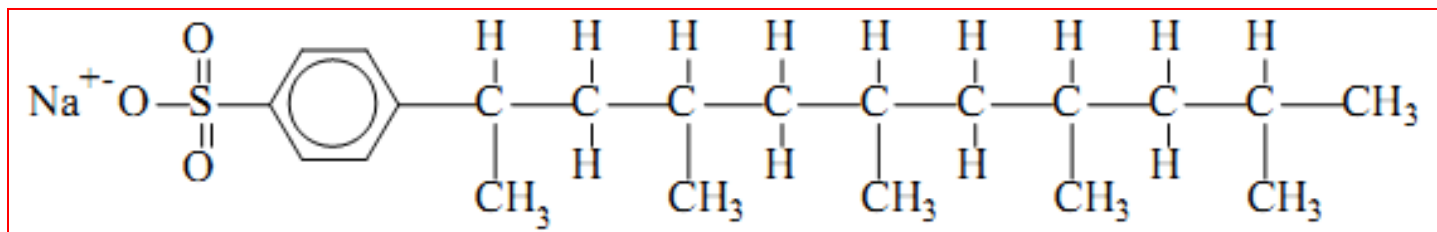
The potential of detergents to contaminate water is high because of their heavy use throughout the consumer, institutional, and industrial markets.

The key ingredient of detergents is the **surfactant or surface-active agent**, which acts in effect to make water “wetter” and a better cleaning agent.

Surfactants concentrate at interfaces of water with gases (air), solids (dirt), and immiscible liquids (oil).

They do so because of their **amphiphilic structure**, meaning that one part of the molecule is a polar or ionic group (head) with a strong affinity for water, and the other part is a hydrocarbon group (tail) with an aversion to water.

This kind of structure is illustrated below for the structure of **alkyl benzene sulfonate (ABS)** surfactant:

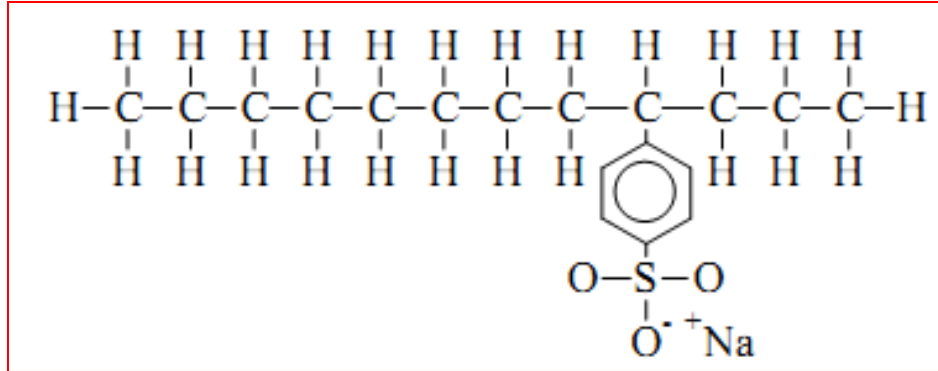


Until the early 1960s, ABS was the most common surfactant used in detergent formulations. However, it suffered the distinct disadvantage of being only very slowly biodegradable because of its branched-chain structure, which is particularly difficult for microorganisms to metabolize.



Consequently, ABS was replaced by a biodegradable surfactant known as **linear alkyl sulfonate LAS**.

LAS,  $\alpha$ -benzenesulfonate, has the general structure



where the benzene ring may be attached at any point on the alkyl chain except at the ends.

**LAS is more biodegradable than ABS because the alkyl portion of LAS is not branched and does not contain the tertiary carbon that is so detrimental to biodegradability.**

## PESTICIDES IN WATER

**Insecticides**, for the control of snails and slugs, مكافحة القواقع والرخويات

**Nematicides** for the control of microscopic roundworms. مكافحة الديدان الدقيقة

**Rodenticides** to control Vertebrates، الفقاريات

**Avicides** used to repel birds, صد الطيور

**piscicides** used in fish control.

**Herbicides** are used to kill plants. Plant growth regulators, defoliants, and plant desiccants are used for various purposes in the cultivation of plants. مكافحة الاعشاب الضارة

**Fungicides** are used against fungi مكافحة الفطريات

**Bactericides** against bacteria مكافحة البكتيريا

**Slimicides** against slime-causing organisms in water الكائنات التي تفرز المواد اللزجة في المياه

**Algicides** against algae الطحالب

Insecticides and fungicides are the most important pesticides with respect to human exposure in food because they are applied shortly before or even after harvesting.

Herbicide production has increased as chemicals have increasingly replaced cultivation of land in the control of weeds and now accounts for the majority of agricultural pesticides.

The potential exists for large quantities of pesticides to enter water either directly, in applications such as mosquito control or indirectly, primarily from drainage of agricultural lands.

### **Natural Product Insecticides, Pyrethrins, and Pyrethroids**

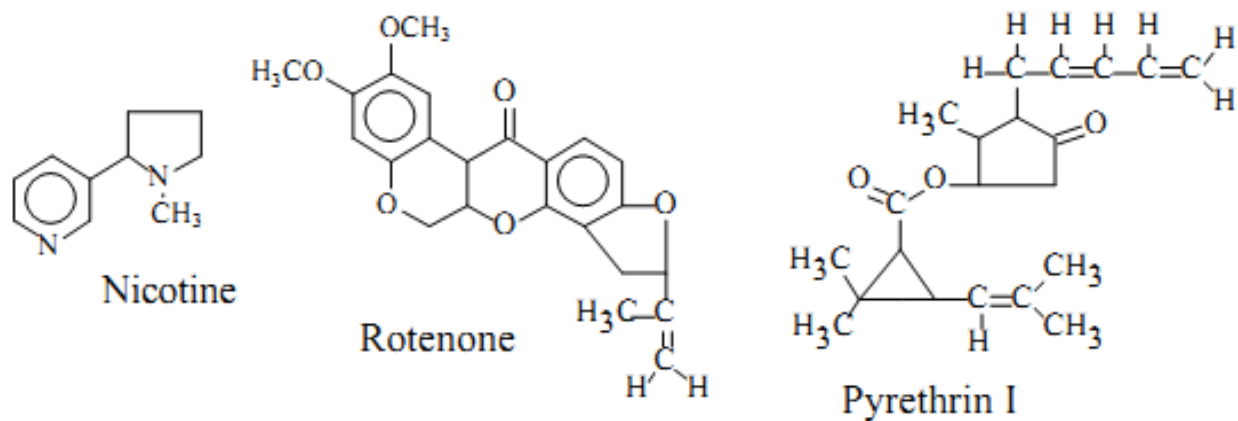
Several significant classes of insecticides are derived from plants.

**Nicotine** from tobacco,

**Rotenone** extracted from certain legume roots

**pyrethrins** extracts of dried chrysanthemum or pyrethrum flowers.

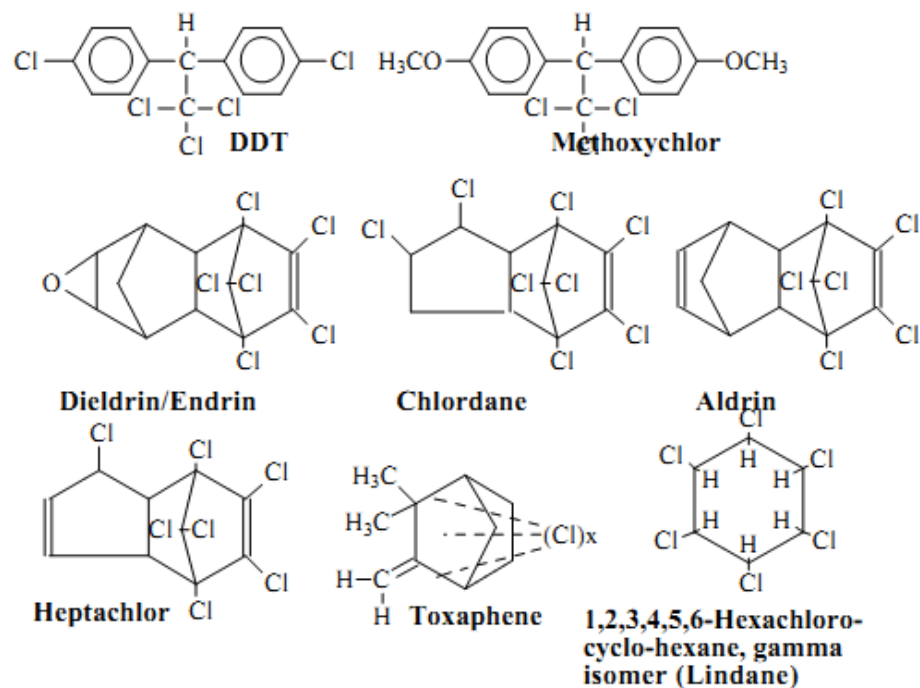
**Because of the ways that they are applied and their biodegradabilities, these substances are unlikely to be significant water pollutants.**



## DDT and Organochlorine Insecticides

Chlorinated hydrocarbon or organochlorine insecticides are hydrocarbon compounds in which various numbers of hydrogen atoms have been replaced by Cl atoms.

The structural formulas of several chlorinated hydrocarbon insecticides are very similar; dieldrin and endrin are stereoisomers (each of two or more compounds differing only in the spatial arrangement of their atoms).



The most commonly used insecticides in the 1960s, these compounds have been largely phased out of general use because of their toxicities, and particularly their accumulation and persistence in food chains.

Of the organochlorine insecticides, the most notable has been DDT (dichlorodiphenyltrichloroethane or 1,1,1-trichloro-2,2-bis(4-chlorophenyl) ethane), which was used in massive quantities following World War II.

**It has a low acute toxicity to mammals التدبيات, although there is some evidence that it might be carcinogenic. It is a very persistent insecticide and accumulates in food chains. It has been banned حظرت in the U.S.**

## RADIONUCLIDES IN THE AQUATIC ENVIRONMENT

The massive production of radionuclides (radioactive isotopes) by weapons and nuclear reactors since World War II has been accompanied by increasing concern about the effects of radioactivity upon health and the environment.

Radionuclides are produced as fission انشطار products of heavy nuclei of such elements as uranium or plutonium.

They are also produced by the reaction of neutrons with stable nuclei.

Radionuclides are formed in large quantities as waste products in nuclear power generation.

Their ultimate disposal is a problem that has caused much controversy جدال regarding the widespread use of nuclear power.

Artificially produced radionuclides are also widely used in industrial and medical applications, particularly as “tracers.” تتبع أثر (كشف)

With so many possible sources of radionuclides, it is impossible to entirely eliminate radioactive contamination of aquatic systems.

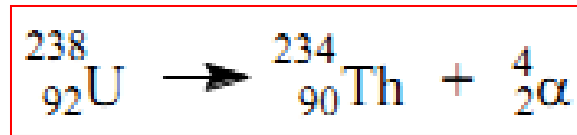
Furthermore, radionuclides may enter aquatic systems from natural sources. Therefore, the transport, reactions, and biological concentration of radionuclides in aquatic ecosystems are of great importance to the environmental chemist.

Radionuclides differ from other nuclei in that they emit ionizing radiation-**alpha** particles, **beta** particles, and **gamma** rays.

**alpha particle** is the most massive of these emissions, a **helium nucleus** of atomic mass 4, consisting of two neutrons and two protons.

The symbol for an alpha particle is  ${}^4_2\alpha$ .

An example of alpha production is found in the radioactive decay of uranium-238:

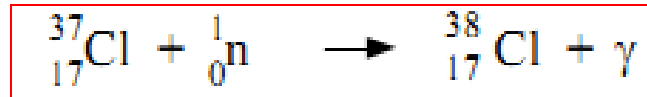


This transformation occurs when a uranium nucleus, atomic number 92 and atomic mass 238, loses an alpha particle, atomic number 2 and atomic mass 4, to yield a **thorium** nucleus, atomic number 90 and atomic mass 234.

**Beta radiation** consists of either highly energetic, negative electrons, which are designated  ${}_{-1}^0\beta$  or positive electrons, called positrons, and designated  ${}_{+1}^0\beta$

A typical beta emitter, chlorine-38, can be produced by irradiating **تَشعيع** chlorine with neutrons.

The chlorine-37 nucleus, natural abundance 24.5%, absorbs a neutron to produce chlorine-38 and gamma radiation:



The chlorine-38 nucleus is radioactive and loses a negative beta particle to become an **argon-38** nucleus:



Since the negative beta particle has essentially no mass and a -1 charge, the stable product isotope, argon-38, has the same mass and a charge 1 greater than chlorine-38.



**Gamma rays** are electromagnetic radiation similar to X-rays, though more energetic.

Since the energy of gamma radiation is often a well-defined property of the emitting nucleus, it may be used in some cases for the qualitative and quantitative analysis of radionuclides.

The primary effect of alpha particles, beta particles, and gamma rays upon materials is the production of ions; therefore, they are called ionizing radiation.

Due to their large size, alpha particles do not penetrate matter deeply, but cause an enormous amount of ionization along their short path of penetration.

Therefore, alpha particles present little hazard outside the body, but are very dangerous when ingested بلعها.

Although beta particles are more penetrating than alpha particles, they produce much less ionization per unit path length.

Gamma rays are much more penetrating than particulate radiation, but cause much less ionization. Their degree of penetration is proportional to their energy.

## Radionuclides in Water

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Radionuclide	Half-life	Nuclear reaction, description, source
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### *Naturally occurring and from cosmic reactions*

Carbon-14	5730 y <sup>1</sup>	$^{14}\text{N}(\text{n},\text{p})^{14}\text{C}$ , <sup>2</sup> thermal neutrons from cosmic or nuclear-weapon sources reacting with $\text{N}_2$
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Silicon-32	~300 y	$^{40}\text{Ar}(\text{p},\text{x})^{32}\text{Si}$ , nuclear spallation (splitting of the nucleus) of atmospheric argon by cosmic-ray protons
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Potassium-40	$\sim 1.4 \times 10^9$ y	0.0119% of natural potassium including potassium in the body
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### *Naturally occurring from $^{238}\text{U}$ series*

Radium-226	1620 y	Diffusion from sediments, atmosphere
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Lead-210	21 y	$^{226}\text{Ra} \rightarrow 6 \text{ steps} \rightarrow ^{210}\text{Pb}$
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Thorium-230	75,200 y	$^{238}\text{U} \rightarrow 3 \text{ steps} \rightarrow ^{230}\text{Th}$ produced <i>in situ</i>
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Thorium-234	24 d	$^{238}\text{U} \rightarrow ^{234}\text{Th}$ produced <i>in situ</i>
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*From reactor and weapons fission*<sup>3</sup>

Strontium-90 (28 y)

Iodine-131 (8 d)

Cesium-137 (30 y)

Barium-140 (13 d) > Zirconium-95 (65 d) > Cerium-141 (33d) > Strontium-89 (51 d)  
> Ruthenium-103 (40 d) > Krypton-85 (10.3 y)

*From nonfission sources*

Cobalt-60

5.25 y

From nonfission neutron reactions in reactors

Manganese-54

310 d

From nonfission neutron reactions in reactors

Iron-55

2.7 y

$^{56}\text{Fe}(n,2n)^{55}\text{Fe}$ , from high-energy neutrons acting on iron in weapons hardware

Plutonium-239

24,300 y

$^{238}\text{U}(n,\gamma)^{239}\text{Pu}$ , neutron capture by uranium

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<sup>1</sup> Abbreviations: y, years; d, days

<sup>2</sup> This notation shows the isotope nitrogen-14 reacting with a neutron, n, giving off a proton, p, and forming the carbon-14 isotope; other nuclear reactions can be deduced from this notation where x represents nuclear fragments from spallation.

<sup>3</sup> The first three fission-product radioisotopes listed below as products of reactor and weapons fission are of most significance because of their high yields and biological activity. The other fission products are listed in generally decreasing order of yield.

Some radionuclides found in water, primarily radium and potassium-40, originate from natural sources, particularly leaching from minerals.

Others come from pollutant sources, primarily nuclear power plants and testing of nuclear weapons.

The levels of radionuclides found in water typically are measured in units of picocuries/liter, where a curie is  $3.7 \times 10^{10}$  disintegrations per second, and a picocurie is  $1 \times 10^{-12}$  that amount, or  $3.7 \times 10^{-2}$  disintegrations per second. (2.2 disintegrations per minute).