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HEAVY METAL CONTAMINATION

*M*any metals occur in traces in the earth's crust. Metals like Pb, Hg, Zn, Cd are heavy metals. Some of the heavy metals are beneficial to organisms in traces. But if excessive levels of heavy metals enter environment through human activities, they endanger health and survival of humans and other organisms. You shall learn about toxic effects of a few heavy metals in this lesson.

Objectives

After reading this lesson, you will be able to

- define heavy metal;
- list the sources of contamination of the environment by heavy metals;
- explain the effects of Pb, Hg, Cd contamination on living organisms and
- list the preventive measures and measures for reduction of heavy metal contamination.

35.1 What is a Heavy Metal?

A heavy metal is one whose density is more than 5g cm^{-3}. Some heavy metals are lead, cadmium, mercury, arsenic selenium, as also iron, copper, manganese, selenium, zinc, etc. All these metals have atomic number greater than 20. Low concentrations of metal like iron, copper, zinc and some others are essential for organisms. They are called 'trace metals'. On the other hand metals like lead, mercury, cadmium and some others are toxic to organisms above a certain concentration.

A trace metal is defined as one which occurs in 1000 ppm (parts per million or mg/litre) or less in the earth's crust.

35.2 Sources of Contamination of Environment by Heavy Metals

Heavy metals are introduced into the environment either by natural means or by human activities.

Natural sources: In nature excessive levels of trace metals may occur by geographical phenomena like volcanic eruptions, weathering of rocks, leaching into rivers, lakes and oceans due to action of water.

Anthropogenic Sources : Small amounts of heavy metals are released while mining and uncontrolled smelting of large quantities of metal, ores in open fires. With the industrial revolution, metals were extracted from natural resources and processed in the industries from where heavy metals passed on into the atmosphere. Similarly traces of heavy metals get into the environment through discharge of waste - both domestic, agricultural and from auto exhausts. Following list shows the various human activities through which heavy metals get into the environment.

(i) Smelting or processing of ores of metals.

(ii) Mining.

(iii) Burning of fossil fuels such as coal, petrol, kerosene oil.

(iv) Discharging agricultural waste.

(v) Discharging industrial waste.

(vi) Discharging domestic waste.

(vii) Discharge from auto exhausts.

(viii) Using pesticides containing compounds (salts) of heavy metals.

35.3 How do Heavy Metals Reach the Ecosystem?

Many toxic inorganic and organic compounds and heavy metals from sources mentioned above, are deposited and buried in the soil by water. They reach the water bodies when washed off from soil by water. Humus, the organic material present in the soil (which also makes the soil look green) has high affinity for heavy metal cations and extract them from water that passes through the soil. Roots of crops and other plants pick up these compounds along with water and pass on to plants and then plants to animals.

Heavy metals are also retained in the soil by adsorption on mineral particles present in the soil and precipitation reactions.

In water, particles with adsorbed heavy metals settle to the bottom and then sediments may accumulate over them. But if organisms consume these, then heavy metals enter the food web.

35.4 Heavy Metal Toxicity

Extraction and trading of metals have been in practice since early days. Heavy metals like iron, copper and lead have been useful in so many ways. With growth of human population, industrialisation, enormous increase in vehicular traffic and use of chemical fertilizers and pesticides, our environment has been contaminated with heavy metals. Heavy metals may also be present in water bodies, under ground water in some areas which are close to the minerals which occur in nature. In our country, several villagers in West Bengal are suffering

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from sores and ulcers due to arsenic poisoning from drinking water. In Minamata, a fishing village in Japan, mercury poisoning hit many villagers.

Heavy metals cannot be removed rapidly from the environment. These are not detoxified (made harmless) by organisms through metabolic activity (biochemical reactions within the body). Heavy metals are also not broken down into simpler products by microorganisms. In other words, they are non-biodegradable. Thus heavy metals accumulate in the environment and have harmful effects on organisms causing heavy metal pollution.

Toxicity depends on the type of heavy metal. Those metals which are insoluble pass through the body without causing much harm. Some metals cause immediate sickness and they are the most dangerous as they do not leave time for treatment. However the worst are those metals which bioaccumlate* and biomagnify** in the food chain, for example, mercury.

* bioaccumulate organisms have a capacity to neutralise some toxins while others are retained in their tissues known as bioaccumulation.

** biomagnify concentration of some toxic metals gradually increase in successive trophic level through food chain. Such biomagnification may make food unsuitable for consumption and thus causes sickness.

Intext Questions 35.1

1. Name any two toxic heavy metals.

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2. Define a heavy metal.

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3. Mention an anthropogenic source of heavy metal pollution.

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35.5 Molecular Basis of Heavy Metals Toxicity

Toxicity in organism is caused by three general mechanisms although the toxic effects on physiology of different organisms. Some of the common mechanisms are :

(i) Metals have strong affinity for sulphur. Sulphydryl (S-H)group is present in some enzymes in the organisms. The metal attaches to S–H group and blocks the active site of the enzyme. The normal functioning of the enzyme gets impaired.

(ii) A heavy metal may displace an essential ion during synthesis of biomolecule. The biomolecule loses its activity e.g. Pb replaces Ca of the bone, making it fragile.

(iii) Metal ions may cause conformational changes in enzymes rendering them inactive.

Toxicity is also caused when the metal blocks the defence proteins of the body which fight infections of organism. Also certain forms of heavy metals can pass through cell membrane protecting vital organs like the brain or foetal membranes in a pregnant mother and cause harm.

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35.6 Effects of Pb, Hg and Cd Contamination

All trace elements have some toxic effects if ingested for a long enough period or at sufficiently high concentrations. We shall now study the sources of contamination and toxic effects of three heavy metals - lead, mercury and cadmium.

Lead : Lead is a very severe pollutant.

Occurance: 0.1% by weight of Pb occurs in the earth's crust in rocks and soil. It occurs naturally in some plants.

Anthropogenic Sources : Human activities have increased the quantity of lead in the environment. Some such anthropogenic sources are:

(i) Soil forms a dumping ground for Pb from mining, smelting, sewage and agricultural sludge;

(ii) From vehicle exhausts: Tetraethyl lead is mixed with petrol for improving efficiency of intemal combustion engines of vehicles. Fuel evaporating from fuel tank and carburetters and unburnt fuel from mopeds and motor bikes release compounds of Pb through automobile exhausts and it accumulates as dust.

(iii) Lead is also released from industries and reaches the soil from accumulating as dust. Pb goes into potable (fit for human consumption) water from lead pipes and lead storage tanks. Pipe joints also have Pb in soldering which may be carried alongwith waterflow.

(iv) It is released from lead acid batteries.

(v) Paints like the yellow lead chromate used for marking roads deteriorate and enter the environment.

(vi) Pottery glazers use lead compounds for glazing. This forms a source of Pb contamination.

Properties : Some of the characteristics of lead pollutants are discussed below:

(i) Lead and its compounds accumulate in the soil. They also bio-accumulate but do not biomagnify.

(ii) They are non-biodegradable.

(iii) They remain in the soil and enter food chain when crops take them up.

Entry into human body: Lead has damaging effects on the human system. It can enter the body in the following ways:

(i) Lead enters human body from canned food and beverages.

(ii) Pb leaches from glazed pottery in acidic media or at high temperatures.

(iii) Surma used in the eyes also has lead.

(iv) Compounds of lead coming out of automobile exhausts enter human through inhalation and skin contact. Children in busy streets show a high lead level in blood. Even breast milk of women living on footpaths have a high lead content.

(v) Lead oxides settle in the soil, in water, on fruits and leafy vegetables from where these easily enter the food chain and reach human body.

Toxic effects of Lead: Lead is a severe toxicant. Some of the toxic effects of lead are discussed below:

(i) After getting into human body lead reaches blood and through circulation gets into soft tissues. Lead however ultimately deposits in the bones replacing calcium,

(ii) Absorption of lead is higher in children and in people suffering from calcium deficiency. It can bioccumulate and remain in the human body for many years. During old age and illness lead moves back from bone to blood to increase level of lead in blood and becomes toxic: It may reach the brain and cause brain damage, convulsion and behavioural disorders.

(iii) Lead interferes with haemoglobin formation and causes anaemia due to deficiency of haemoglobin. Lack of haemoglobin may further cause kidney and brain damage.

(iv) Acute toxicity of lead maybe fatal.

Mercury

Metallic mercury is relatively inert and nontoxic. On inhalation it reaches blood and them to central nervous system and causes severe damage.

Occurance : Mercury is present in the earth's crust. It also reaches the environment from volcanic gases and evaporation from oceans. Mercury exists as metallic mercury, inorganic salt, and organic methyl mercury. Soil bound mercury is converted into dimethyl mercury by the action of anaerobic bacteria. Mercury is also present in traces in fossil fuel and minerals. Plants take up mercury from soil and release it as mercury vapour during transpiration as mercury is volatile.

Anthropogenic Sources: Mercury has been in the environment for long even earlier than the 20th century. It reaches the environment in the following ways:

(i) While extracting gold and mercury from the ores.

(ii) Burning of fossil fuels releases mercury vapours into the environment. Coal in India has a high mercury content. If low grade coal is used in thermal power plants, mercury which has a high vapour pressure and high combustion temperature escapes into the atmosphere and condenses as dust particles.

(iii) Wastes from paper, plastic, caustic soda and chlorine industries release mercury into the environment.

(iv) Mercury compounds are used as fungicides or pesticides because of their toxicity and thus finds ways to environment.

(v) Electrical appliances : Mercury is excellent conductor of electricity, so it is used in electric switches, lamps and batteries. Such appliances are potential source for the release of mercury vapours.

Entry of Hg into plants, animals and humans : Hg reaches plants from soil when it is taken up by roots. Plants may also take up mercury vapour from air through the stomata (pores) on the leaves. In animals mercury reaches the tissues as it is soluble in fatty acids

which form the components of cell membranes of all cells of a tissue. Mercury bio-accumulates and biomagnifies. In humans it enters through the food chain, mainly through the consumption of fish. In fish it is present in the form of methyl mercury.

Toxic effects of Mercury: People in Japan suffered from a disease called Minamata disease due to consumption of mercury poisoned fish.

Minamata disease: In Japan in 1953 mercury poisoning occurred due to consumption of fish which had died of Hg poisoning. Mercury had contaminated the water where it had reached as effluent of a vinyl chloride (ingredient of plastic) factory. Fishermen living in coastal areas of Minamata Bay had eaten the dead fish. They suffered from Minamata disease, whose symptoms were weakened muscles, impaired vision, mental retardation, paralysis and death.

Mercury is non toxic when swallowed but if inhaled in its volatile form it enters brain through blood stream, causing damage to nervous system. Hence mercury should be handled in a well ventilated room and cleaned up if spilt. Hg ions have affinity for sulphur and cause harm by attaching to sulphur containing amino acid of proteins. Hg ions also bond with haemoglobin and other blood proteins especially those containing sulphydryl groups.

Most toxic to humans are the organo-mercury compounds especially methyl mercury as it disolves in fatty tissues and bio-accumulates and bio-magnifies. Microorganisms convert high levels of inorganic mercury into the organic derivatives like dimethyl mercury. Methyl mercury compounds are very toxic because of the following reasons :

(i) These compounds can reach brain and interfere with transmission of nerve impulses

(ii) These compounds can cause permanent damage to the central nervous system of foetus of pregnant mothers.

(iii) These compounds also cause increased loss of water from kidney and ultimately causes to death.

Cadmium : Cadmium is highly toxic metal.

Occurrence : The natural sources of cadmium are volcanic activity, spray from oceans and forest fires.

Anthropogenic Sources : Humans activity add more cadmium to atmosphere than natural sources. Coal mining, non-ferrous metal mining, refineries, coal combustion, burning of refuse (water matter) iron and steel industries and phosphate fertilizers are main sources of cadmium. Tobacco containing cadmium is finely dispersed in air when released with cigarette smoke. Cadmium is chemically very similar to zinc. It also occurs with zinc minerals.

Entry of Cadmium into Plants, Animals and Humans

Plants requiring zinc pick up cadmium along with zinc as cadmium occurs alongwith Cadmium, thus enters the food chain. Cadmium in present in from potatoes, wheat, rice and other grains. Sea food also have a high level of cadmium.

Humans get cadmium in their system from tobacco smoking and from tobacco chewing Tobacco leaves absorb cadmium from irrigation water.

Individuals living near and working for mines and smelters processing zinc and electroplating face a heavy risk of cadmium toxicity. Cadmium is soluble in water and reaches the humans working in zinc mines.

Toxic Effects of Cadmium: Cadmium is a cumulative poison. It is retained in the body for a long time and causes

(i) hypertension (high blood pressure),

(ii) heart ailments

(iii) kidney damage

(iv) destruction of red blood cells

(v) damaged mitochondrial function of cells.

Cadmium resembles zinc chemically Ca^{2+} and Cd^{2+} share the same charge and have similar sizer. It may therefore replace zinc in enzymes and thus destroy their catalytic activity. In Japan, people got a bone disease "itai itai" where Ca^{++} of bones were replaced by Cd^{++}.

35.7 How to Prevent Heavy Metal Toxicity

To save human lives and other organisms from disasters due to toxic effects of heavy metals, preventive measures need to be enforced. Government of India has set up in January 1985, a separate Ministry of Environment and Forests which looks into the issues of environment. Several non-government agencies are also busy educating people about the ill effects of metal and other pollution and the ways to prevent it.

Industries have been asked to take steps for proper disposal of industrial waste. Special devices have been designed for removal of effluents. The government has decided to take penal action against industries which do not install proper devices and dump waste in the rivers or on soil. Efforts are underway to gradually phase out the use of leaded petrol. Newly manufactured cars have been designed to use lead-free petrol. Catalytic converters have been designed for using lead free petrol in the old cars.

35.8 How to Remove Metal Pollution

It is very difficult to remove metal pollutants as metals are present in a very low concentration, There are however, two ways of designing systems for removal of metal pollution:

(i) design process for removal of one metal or

(ii) design one process which removes several metals.

For rivers and sediments contaminted by heavy metals; the following have been suggested.

(i) Place layers of uncontaminated clean soil over contaminated sediment so that the metal containing sediment may not get washed away by rivers.

(ii) Treating with $CaCO_3$ which increases pH of the sediment and immobilises heavy metals.

(iii) Limestone, gypsum, iron sulphate and activated charcoal can be used as detoxifying.

(iv) Using water Plants such as *pistia* and *hydrilla* which pick up mercury from water bodies and help in reducing mercury-pollution.

Intext Questions 35.2

(1) What causes Minamata disease?

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(2) List three sources of lead pollution.

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(3) Name the mercury derivative which is very toxic to human.

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(4) Mention two water plants by which mercury pollution can be reduced?

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What You Have Learnt

- Heavy metals occur in earth's crust in traces. Their excess in the environment harm living organisms.
- Heavy metal is one whose density exceeds 5g cm^{-3}.
- A trace metal occurs in 1000 ppm or less in the earth's crust.
- In nature, heavy metals accumulate in soil by natural phenomena like volcanic activity, weathering of rocks, action of wind, water etc.
- The anthropogenic sources for metal pollution are mining, smelting, fossil fuel burning, discharging agricultural, industrial and domestic wastes, auto exhausts etc.
- Heavy metals reach ecosystem from soil and water and enter humans and other organisms through food chain.
- Heavy metals cannot be removed rapidly from environment as they are neither detoxified nor biodegraded. Instead some of them bioaccumulate and biomagnify.
- At the molecular level, metals become toxic as they impair the proper functioning of enzymes by attaching to S-H group of the enzyme or causing conformational changes in them. A heavy metal may displace an essential ion.
- Pb is released from industries or from Pb pipes or leaded petrol. It causes nervous disorders.
- Hg comes into environment from plastic, paper, chlorine industries. Methyl mercury: is especially dangerous to humans which they might get through food chains. It causes nerve damage and kidney disorders. In Japan Hg toxicity caused Minamata disease.

- Cadmium is toxic. It enters the environment through coal mining, coal combustion, burning of refuse, fertilisers etc. Cd causes hypertension. In Japan Cd caused a disease itai-itai.
- Heavy metal toxicity can be prevented by proper disposal of industrial effluents, use of unleaded petrol and educating masses about toxicity of metals. Metals already accumulated can be removed by using aquatic plants which take them up or by covering contaminated sediments with clean soil.

Terminal Exercise

1. List five human activities which release heavy metals into the environment.
2. How do heavy metals reach the ecosystem?
3. Relate a molecular, mechanism by which a heavy metal becomes toxic.
4. How does cadmium accumulate in the environment? What kind of effect does it have on human body?
5. List five sources of lead pollution. Mention two of its adverse effects.
6. Mention two toxic effects of mercury contamination.
7. Write a note on Minamata disease.
8. How can heavy metal pollution be checked?

Answers to Intext Questions

35.1

1. Any two from Cd, Hg, and Pb
2. A heavy metal is one whose density is greater than 5g cm^{-3}.
3. Anyone from, mining, auto exhaust, paper, plastic, paint factories.

35.2

1. Hg
2. Refer to section 35.2
3. Methyl mercury
4. Pistia, Hydrilla