Heavy Metals: Environmental Threat

Heavy metals are important among the toxic pollutants encountered in various ecosystems of the environment. The dissolved metals (particularly heavy metals) escaping into the environment pose a serious health hazard. These metals have been classified as priority pollutants by the US Environmental Protection Agency. Heavy metal pollution in the aquatic system has become a serious threat today and of great environmental concern as they are non-biodegradable and thus persistent. They accumulate in living tissues throughout the food chain which has humans at its top, multiplying the danger. Thus, it is necessary to control presence of heavy metals in the environment (Fig. 1).

From an environmental pollution point of view, metals may be classified into the following categories:

Non-toxic but accessible
Toxic but non-accessible
Toxic and accessible

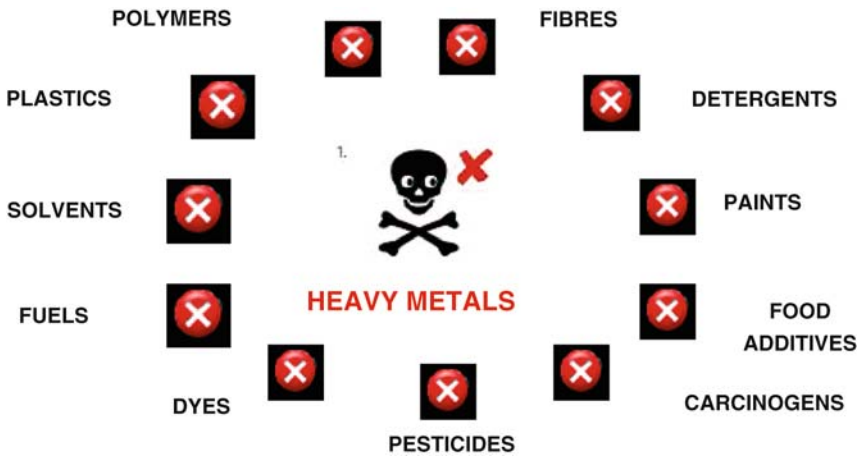

Fig. 1 Pollution: A prize tag of modern society

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It is the third category of potentially toxic and relatively accessible metals that has attracted the keen attention of the researchers. These toxic metals occur in very small quantities in the Earth's crust and hence are called rare metals. These are further arbitrarily subdivided on the basis of their densities. Those having densities less than 5 g/cm^3 are designated as light metals while those having densities more than 5 g/cm^3 are designated as heavy metals. Thus metals like Hg, Cd, Cr, Ni, and Pb are generally known as toxic heavy metals. Surprisingly, even metalloids like Se, As, and Sb are also considered under this category, thereby making the term heavy metals misleading. When considering the environmental impacts of metallic species, Pb, Cd, Cr, Ni, and As are in focus. They can enter the human beings via food chain and often exceed the toxic levels before they produce visible toxic effects. *World Health Organization* has, recently, recognized the health hazards of toxic metals in food chain even at low concentrations. Environmental Protection Agency's "Top 20 Hazardous Substance Priority List" has ranked mercury as 6th, cadmium 7th, chromium 8th, and nickel 13th, while quoting arsenic as the king of poisons.

The toxic and deleterious effects of metals are measured by its dose–response relationship, where response is the sign of an adverse effect (Fig. 2). The curve in Fig. 2 illustrates the relationship between amount and effect (response). Till date, it is debatable at what levels an effect can be considered as catastrophic. The situation continually changes as the sensitivity of measurements increases and very small effects are recognized.

Heavy metals have been reviewed thoroughly in a voluminous manner in the literature. Therefore, important features of target metals like their *physical and chemical properties, environmental sources, environmental concentrations*, and *toxicity* along with *permissible limit* have been presented in a concise manner.

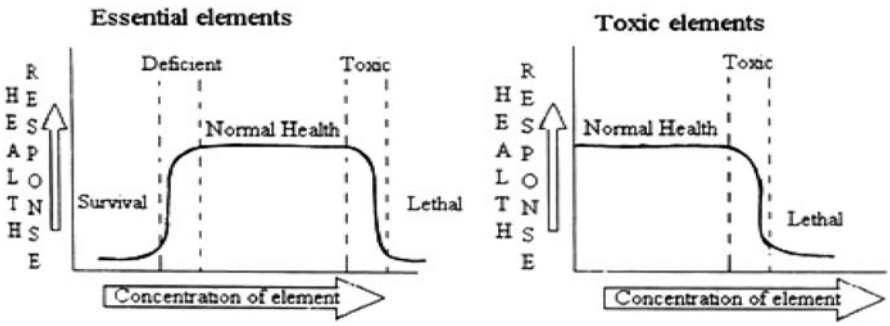
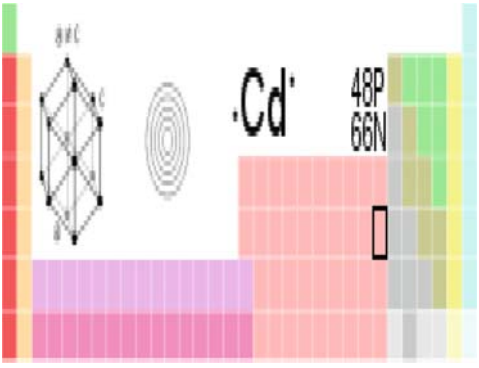


Fig. 2 The relationship between health response and the concentration of the elements – essential elements and toxic elements (Source: Adeloju and Bond, 1985)

Cadmium

Cadmium has been ranked as *seventh* in the Environmental Protection Agency's "Top Hazardous Substance Priority List."

Cadmium was discovered in Germany in 1817 by *Friedrich Strohmeyer*. Cadmium is odorless, tasteless, and chemical analysis is most often required to detect its presence. Remarkable characteristics of cadmium involve its great resistance to corrosion, low melting point, and excellent electrical conductivity because of which it plays a critical role in several cutting-edge technologies such as solar cells. Cadmium is one of the few elements that have no constructive purpose in the human body.



General Properties	
Symbol	Cd
Atomic number	48
Group, period, block	12,5,d
Electronic configuration	[Kr] $4d^{10}5s^2$
Appearance	Silvery grey metallic
Atomic Properties	
Crystal structure	Hexagonal
Electronegativity	1.69
Atomic radius	0.161 nm
Ionic radius	0.097 nm
Covalent radius	0.148 nm
Physical Properties	
Characteristics	Malleable and ductile
Phase	Solid
Density	8.65 g cm^{-3}
Chemical Properties	
Atomic mass	112.41 g/mol^{-1}
Melting Point	321 ^{0}C
Boiling Point	767 ^{0}C
Standard Potential	–0.402 V

Environmental Concentrations

Air

Rural area : 0.1–5 ng/m^3
Urban area : 2–15 ng/m^3
Industrial area : 15–50 ng/m^3

Water

Sea water : ~0.1 mg/L
Fresh water : 1–10 mg/L
Industrial water : 10–100 mg/L

Soil : 3–750 ppm

CADMIUM

Environmental Sources

Natural

Weathering of rocks
Volcanic eruptions
Fall out

Anthropogenic

Ni-Cd batteries
Pigments
Coatings
Stabilizers
Fertilizers

Government Standards and Guidelines

The Environmental Protection Agency (EPA) allows 5 parts of cadmium per billion parts of drinking water (5 ppb).

The Food and Drug Administration (FDA) limits 15 parts of cadmium per million parts of food color (15 ppm).

The Occupational Safety and Health Administration (OSHA) limits workplace air to 100 micrograms (µg) cadmium per cubic meter (100 µg/m^3).

Itai-Itai disease

Health Effects

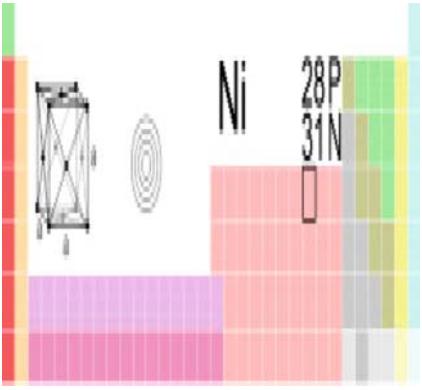
- Itai-Itai
- Muscle cramps
- Fragile bones
- Lungs and Kidney malfunctioning
- Liver injury
- Sensory disturbance
- Carcinogenicity
- Mutagenicity
- Affect cardiovascular system
- High blood pressure

Source: Agency for Toxic Substances and Disease Registry (ATSDR), 2007.

Nickel

Nickel has been ranked as *53rd* in the Environmental Protection Agency's "Top Hazardous Substance Priority List."

Nickel is the world's 24th most abundant transition metal. The element was discovered unintentionally in 1751 by *Baron Axel Frederick Cronstedt*, who extracted it from a mineral called *Niccolite*. Nickel can be combined with other elements such as iron, copper, chromium, and zinc to form alloys. These alloys are used to make coins, jewelry, and items such as valves and heat exchangers. Many nickel compounds dissolve fairly easily in water and have a green color. The most important oxidation state of nickel is +2.



General Properties	
Symbol	Ni
Atomic number	28
Group, period, block	10,4,d
Electronic configuration	[Ar] $3d^8$ $4s^2$
Appearance	silvery metallic
Atomic properties	
Crystal structure	Face centered cubic
Electronegativity	1.91
Atomic radius	.149 nm
Ionic radius	0.069 nm
Covalent radius	0.121 nm
Physical properties	
Characteristics	Lustrous and hard
Phase	Solid
Density	8.9 g cm^{-3}
Chemical properties	
Atomic mass	58.71 g/mol^{-1}
Melting Point	1453^{0}C
Boiling Point	2913^{0}C
Standard Potential	–0.25 V

Environmental Concentrations

Air

Electrolysis sector : 0.4 mg/m^3
Urban area : 17–25 mg/m^3
Industrial area : 120–170 mg/m^3

Water

Sea water : 0.1–20 mg/L
Drinking water : 0.7 mg/L
Industrial water : 1–100mg/L

Soils : 3–1000 ppm

NICKEL

Environmental Sources

Natural

Weathering of rocks
Volcanic eruptions
Fall out, Meteorites

Anthropogenic

Roasting plants
Smelting plants
Electroplating
Steel industry
Batteries
Oil Hydrogenation

Government Standards and Guidelines

The Environmental Protection Agency (EPA) recommends that drinking water should not contain more than 0.7 milligrams of nickel per liter of water (0.7mg/L).

The Occupational Safety and Health Administration (OSHA) limits workplace air to 1 µg of nickel per cubic meter (1 µg/m^3).

Environmental Toxicity

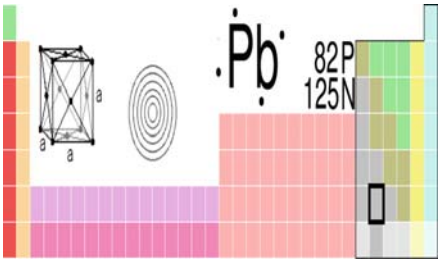
- Dental Prostheses
- Acute poisoning
- Dermatitis
- Asthma
- Respiratory cancer
- Malignant neoplasm
- Lung embolism
- Asthma and bronchitis
- Heart disorders

Source: Agency for Toxic Substances and Disease Registry (ATSDR), 2007.

Lead

> Lead has been ranked as *second* in the Environmental Protection Agency's "Top Hazardous Substance Priority List."

Metallic lead does occur in nature, but it is rare. Lead is usually found in *ore* with *zinc*, *silver*, and (most abundantly) *copper* and is extracted together with these metals. The main lead *mineral* is *galena* (PbS), which contains 86.6% lead. Lead has many *isotopes* but four stable ones. The four stable isotopes are ^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb, with ^{204}Pb regarded as primordial Pb while 206, 207, and 208 are formed from the decay of U and Th.



General Properties	
Symbol	Pb
Atomic number	82
Group, period, block	14,6,p
Electronic configuration	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^2$
Appearance	Bluish gray
Atomic properties	
Crystal structure	Cubic face centered
Electronegativity	2.33
Atomic radius	0.180 nm
Ionic radius	0.069 nm
Covalent radius	0.147 nm
Physical properties	
Characteristics	Lustrous and soft
Phase	Solid
Density	11.34 g cm^{-3}
Chemical properties	
Atomic mass	207.20 g/mol^{-1}
Melting Point	327.46^{0}C
Boiling Point	1749^{0}C
Standard Potential	–0.25 V

Environmental Concentrations

Air

Rural area : 0.1-5 ng/m^3
Urban area : 2-15 ng/m^3
Industrial area : 15-50 ng/m^3

Water

Sea water : ~0.1 mg/L
Fresh water : 1-10 mg/L
Industrial water : 10-100 mg/L

Soil : 7–300 ppm

L E A D

Environmental Sources

Natural
Weathering of rocks
Volcanic eruptions
Fall out, Meteorites

Anthropogenic
Lead-acid batteries,
bullets and shot
Fusible alloys
Paint pigments

Government Standards and Guidelines

The Environmental Protection Agency (EPA) allows 15 parts of lead per billion parts of drinking water (15 ppb).

The Food and Drug Administration (FDA) limits 5 parts of lead per billion parts of food color (5 ppb).

The Occupational Safety and Health Administration (OSHA) limits workplace air to 100 micrograms (µg) cadmium per cubic meter (100 µg/m^3).

Environmental Toxicity

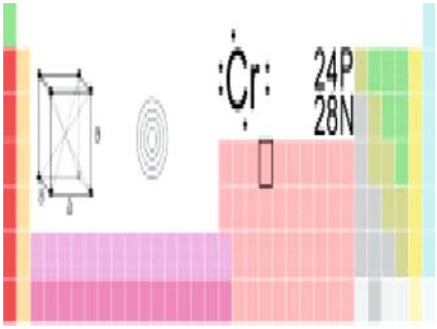
- Blood and brain disorders Nepheropathy
- Colic-like abdominal pains
- Cognitive deficits in children
- Muscle and joint pain Irritability
- Memory or concentration problems
- Swelling of Kidney
-

Source: Agency for Toxic Substances and Disease Registry (ATSDR), 2007.

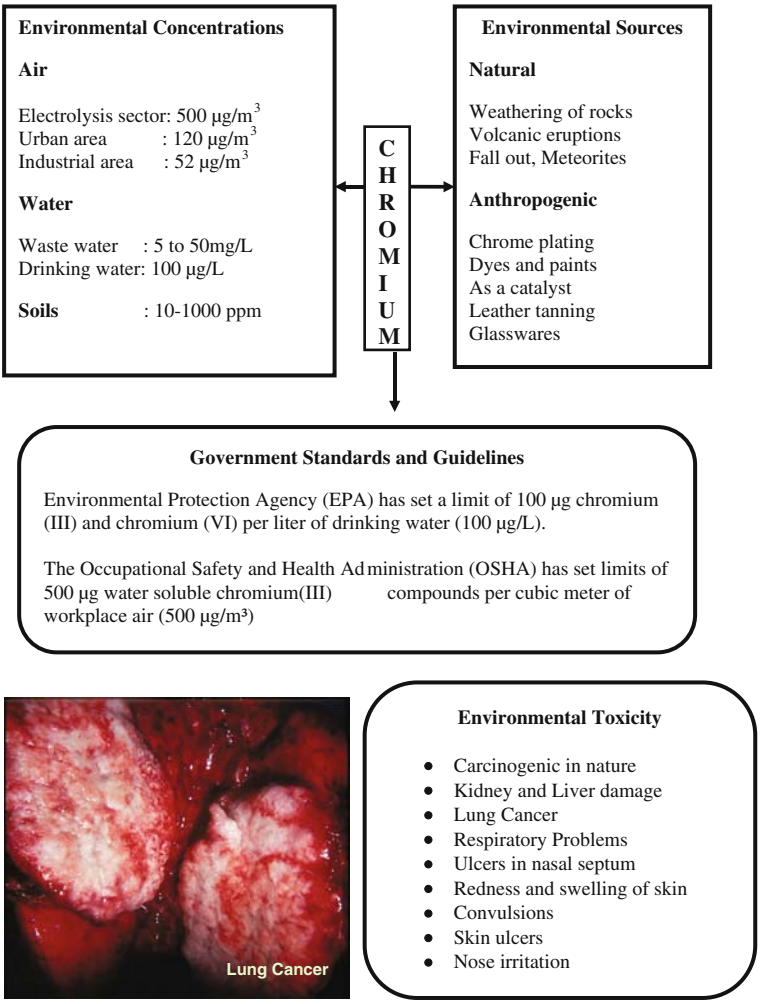
Chromium

Chromium has been ranked as *18th* in the Environmental Protection Agency's "Top Hazardous Substance Priority List."

Chromium was discovered by the French chemist *Nicholas Louis Vauquelin* in 1797. The most common oxidation states of chromium are +2, +3, and +6, with +3 being the most stable. The oxidation states +4 and +5 are relatively rare. Chromium compounds of +6 oxidation states are powerful oxidizing agents. Chrome metal (chromium 0) is the element that makes steel "stainless."



General Properties	
Symbol	Cr
Atomic number	24
Group, period, block	6,4,d
Electronic configuration	[Ar] $3d^4$ $4s^2$
Appearance	Silvery metallic
Atomic properties	
Crystal structure	cubic body centered
Electronegativity	1.6
Atomic radius	.166 nm
Ionic radius	0.061 nm
Covalent radius	0.127 nm
Physical properties	
Characteristics	Lustrous and brittle
Phase	Solid
Density	7.19 g cm^{-3}
Chemical properties	
Atomic mass	51.99 g/mol^{-1}
Melting Point	1907^0C
Boiling Point	2672^0C
Standard Potential	–0.402 V



Source: Agency for Toxic Substances and Disease Registry (ATSDR), 2007.