# Elements in Biology

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Research findings suggest that eleven elements are predominantly present in all biological systems. However, hydrogen, carbon, oxygen and nitrogen correspond to 99% of the total. Hydrogen constitutes 62.8% of the atoms in a human body. The percentage of oxygen, carbon and nitrogen are 25.4, 9.4 and 1.4%, respectively. Other essential elements make up the remaining 1% {sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), sulphur (S) and chlorine (Cl)}. Very large percentages of hydrogen and oxygen arise from the high-water content present in living systems. Regarding our health and well-being, it is important to know about the elements found in biological systems, their functions and the level of toxicity.

## Biological functions of elements

Many important life processes require metal ions. These processes include respiration, metabolism, nitrogen fixation, photosynthesis, life development, nerve transmission, muscle contraction, signal transduction and protection against toxic and mutagenic agents. Biological functions of some selected elements are given in Table 1.

**Table 1.** Biological functions of some elements

| Metal | Functions |
|---|---|
| Na, K | charge carrier, enzyme activator |
| Mg | enzyme activator, metal center found in chlorophyll |
| Ca | component of bone and shell, messenger for hormone action, trigger for muscle contraction, involves in cell secretion and neurotransmission |
| As | enzyme inhibitor |
| Fe, Cu | found in active sites in redox metalloenzymes and dioxygen-carrying proteins |
| Mo | found in redox enzymes and nitrogenase |
| Mn, Zn | found in several enzymes |
| Co | essential component of vitamin-$B_{12}$ |
| Hg, Pb, Cd | enzyme inhibitor |

Enzymes are biological catalysts and are produced inside the living body and catalyze biochemical reactions. Sometimes these enzymes combine with metals to perform their functions; such enzymes are called metalloenzymes. Some metalloenzymes and their biological functions are given in Table 2.

**Table 2.** Some metalloenzymes and their biological functions

| Metal | Enzyme/ biomolecule | Biological Function |
|---|---|---|
| Fe | Ferredoxin, Succinate dehydrogenase | photosynthesis, aerobic oxidation of carbohydrate |
| Fe in haem | Aldehyde oxidase, Cytochromes Catalase | aldehyde oxidation, electron transfer, protection against $H_2O_2$ |
| Cu | Ceruloplasmin, Cytochrome oxidase, Tyrosinase, Plastocyanin, Lysine oxidase | iron utilization, photosynthesis, skin pigmentation |
| Zn | Carbonic anhydrase, Carboxy peptidase, Alcohol dehydrogenase | $CO_2$ formation, regulation of acidity, protein digestion, alcohol metabolism |
| Mn | Arginase, Pyruvate carboxylase | urea formation, pyruvate metabolism |
| Co | Ribonucleotide reductase, Glutamate mutase | DNA biosynthesis, amino acid metabolism |
| Mo | Xanthine oxidase, Nitrate reductase | purine metabolism, nitrate utilization |
| Ca | Lipases | lipid digestion |
| Mg | Hexokinase | phosphate transfer |

## Essential metallic elements in biological systems

In the Periodic Table, there are about 118 elements. About 30 elements are recognized as being essential to

some form of life. Na, K, Mg and Ca are classified as bulk metals and Fe, Co, Mn, Zn, Cu, Mo, Cr, Sn, V and Ni as **essential trace metals**.

**Bulk metal ions: Na, K, Mg and Ca**

These bulk metal ions are derived from the *s*-block. These are the most abundant metal ions in biology. They occur in most cells in fairly high concentrations. Sodium and potassium play very important biochemical roles in biological systems. They serve as charge carriers and they are also important in maintaining the osmotic balance of the body.

**Sodium and potassium**

After calcium, potassium and sodium are the second and third most important cations respectively in the human body. A typical 70 kg human being contains about 20 g of sodium and 170 g of potassium. Na ions are found primarily on the outside of cells, mainly in blood plasma and in the intestinal fluid which surrounds the cell.

**Magnesium**

An adult body contains about 25 g of magnesium. About 60% of magnesium is present in the skeleton while the remainder resides inside the cells where it is the next most important cation after potassium. The daily requirement in the human diet is about 200-300 mg. Magnesia is used as antacids. A mixture (Maalox) containing magnesium hydroxide and aluminium hydroxide is also used as an antacid. The actions of this mixture last long because the bases are released slowly as they are relatively insoluble.

**Calcium**

Calcium is the most predominant metal in the human body. It is present in high concentrations in extra cellular and intra cellular fluids. About 99% of body calcium is present in bones and teeth. This metal also plays extremely important roles in neuromuscular function, inter-neuronal transmission, cell-membrane integrity and blood coagulation. The minimum daily requirement of calcium intake for an adult is 400-600 mg.

A human skeleton contains 1.1-1.5 kg of calcium; present mainly as hydroxyapatite [$Ca_5(PO_4)_3(OH)$]. The mineralized portion of the skeleton is mainly formed either from hydroxyapatite or calcium phosphate.

**Essential/trace metals**

Brief account of essential and/or trace metals is as follows.

**Iron**

Iron has a wide range of biological activity. About 5 g of iron is present in an adult human body of which 3-4 g is in red blood cells as the oxygen carrying protein (haemoglobin) and 1 g is stored as ferritin and haemosiderin (or hemosiderin). Decrease in iron intake or an increase in iron loss produces anaemia and wide variety of clinical situations.

**Copper**

There are about 60 mg of copper in an adult human. These are mainly present in a range of metalloproteins distributed throughout the body. The average daily diet provides 0.5-1.0 mg of copper which, after absorption through the intestine, is carried to the liver by two transport proteins (*e.g.*, albumin and transcaspian) present in the plasma.

**Zinc**

Zn is essential for the normal growth and development of mammals. It is present in human body to the extent of 1.4 - 2.3 g.

**Cobalt**

Cobalt is known as an essential element since 1930's. It is an essential component of vitamin $B_{12}$. All vitamin $B_{12}$ analogues are produced by microorganisms. Radioactive isotope cobalt-60 is widely used for the treatment of cancer.

**Molybdenum**

Molybdenum is an essential micronutrient for microorganisms, plants and animals. Molybdenum is a relatively poor oxidant. It is very important to many enzymes, including xanthine oxidase, aldehyde reductase, and nitrate reductase.

**Non-metallic elements in biological systems**

The essential non-metallic elements are H, B, C, N,

O, F, Si, P, S, Cl, Se and I. These non-metals in biology belong to *p*-block. Most of the important small molecules (*i.e.*, $O_2$, $N_2$, $CO_2$ and $H_2O$) in our environment are related to p-block elements.

**Hydrogen**

Hydrogen is involved in many life processes and it is ready to share its 1s electron with C, N, and O without conferring any structural complexities. When bonded to nitrogen and oxygen, it has the ability to form strong hydrogen bonds between molecules. The boiling point of water is relatively high due to inter-molecular hydrogen bonding. Hydrogen bonding plays a vital role in biological processes.

**Carbon, nitrogen and oxygen**

Carbon is unique among the elements due to its dual ability to catenate (to form molecules with a long chain of carbon atoms), producing aliphatic chains and rings and to form molecules with strong π bonds with itself and also with nitrogen and oxygen. All three elements are involved in the formation of (i) amino acids required for protein synthesis, (ii) purines and pyrimidine bases for the synthesis of nucleic acids, and (iii) multidentate ligands with porphyrin and corrin ring systems in haemoglobin and chlorophyll, respectively.

**Silicon**

Silicon is the second most abundant element in the Earth's crust after oxygen. It has wide implications in plant biology. The effects of Si range from regulation of development to protection of plants from various types of stresses.

**Phosphorus**

Phosphorus plays a vital role in all life forms. Phosphate esters and diesters are the principal mode in which it performs its essential functions.

**Sulphur**

It is an essential macronutrient required for the growth and development of all living organisms. It is present in a wide variety of metabolites important for the maintenance of cell structure and biological activities. It is present in amino acids such as cysteine and methionine.

**Boron**

Boron is present in small amounts in soil, water and food. It has been known to be essential for plants for a long time. Human needs 2-3 mg of boron per day.

**Iodine**

Iodine is the heaviest of the essential elements being a necessary constituent of the thyroid hormones, thyroxine and triiodothyronine. Most of the iodine present in humans is bound to a protein, thyroglobulin and to the thyroid gland.

**Metals in medicine**

A few elements have become of marked clinical value. Clinically used two important inorganic pharmaceuticals are lithium carbonate and cisplatin, *cis*-$[PtCl_2(NH_3)_2]$. These metals do not have any known biological functions. Platinum and gold complexes are used for the treatment of tumours and rheumatoid arthritis, respectively. Compounds of radioactive metals, for example, technetium-99m, are used as imaging agents. Complexes of gadolinium are now used as MRI contrast agents for the diagnosis of disease.

**Lithium**

Lithium as $Li_2CO_3$ is used for the treatment of manic-depressive psychos. Doses of 0.25 to 1 g per day are taken to maintain a plasma lithium concentration of 0.5-1.0 mmol $dm^{-3}$. Symptoms of toxicity are observed at about 2 mmol $dm^{-3}$ leading to cause tremor of hands, polyuria, vomiting, diarrhoea, sluggishness, vertigo and slurred speech.

**Gold**

The history of biological use of gold goes as far back as 2500 BC In 1890, Koch observed the inhibition of the growth of Tuberculosis bacilli by gold cyanides. It was the beginning of systematic gold pharmacology with designing gold-based drugs. Since 1940, complexes of gold have been used successfully to treat arthritic disorders in humans and other animals. Au(I) compounds are known to cease the progression of rheumatoid arthritics. $[Au(CN)_2]^-$ has shown potent bacteriostatic properties, *i.e.*, it retards the growth of bacteria without killing them. Gold-phosphine complexes have also shown anti-tumour

activity.

**Platinum**

Some complexes of Pt(II) and Pt(IV) are potent antitumour agents. Cisplatin can cause complete tumour regression and it is known since 1965. Cisplatin forms different types of Pt-DNA adducts.

**Technetium**

Technetium (Tc) complexes fulfil the requirement of an ideal diagnostic agent. About 90% of clinical diagnostic imaging procedures involve Tc. 99mTc is an easily detectable powerful γ emitter. It is short lived (half-life = 6 h) and photons emitted can penetrate without damaging tissue.

It has been observed that different Tc complexes become localized in specific tissues and cells, particularly with abnormalities. The radioactive Tc complexes are injected into the patient's blood vessels. After about three hours, the Tc clears from the blood and soft tissues, and accumulates in bones, which is then scanned to locate the abnormal cells.

**Radioisotopes**

The first use of radioisotopes in medicine was reported in 1930. Radioactive iodine was used to assess the percentage of radioactive iodine-131 located in the thyroid with respect to the dose administered. Radioisotopes are being used for detection and treatment of various illnesses and some applications are given in Table 3.

**Table 3.** Some radioisotopes and their applications in medicine

| Isotope | Uses |
|---|---|
| $^{74}As$ | Locate brain tumours |
| $^{51}Cr$ | Determine total blood volume |
| $^{58}Co$ | Determine uptake of Vitamin $B_{12}$ |
| $^{60}Co$ | Radiation treatment of cancer |
| $^{131}I$ | Treatment of thyroid cancer |
| $^{24}Na$ | Detect obstructions in the blood circulation |
| $^{226}Ra$ | Radiation treatment of cancer |

**Potential toxic elements**

Some elements are highly toxic. All toxic elements are chemically similar to essential elements and therefore interfere with the function of the essential element. The two similar elements may be in the same group of the periodic table or have the same size ions.

**Arsenic**

Arsenic is a potential poison as well as an essential element. Complete absence of arsenic in diet leads to growth and reproductive disorders. Arsenic occurs naturally as non-toxic arseno-lipids in fish and lobsters. However, arsenic is toxic in its inorganic form ($As^{3+}$). Contaminated water used for drinking, food preparation and irrigation of food crops poses the greatest threat to public health. Long-term exposure to arsenic from drinking-water and food can cause cancer and skin lesions.

**Cadmium**

Cadmium salts are known to be toxic. Long-term exposure to cadmium through air, water, soil, and food leads to cancer and organ system toxicity.

**Chromium**

When inhaled, chromium compounds are respiratory tract irritants and can cause pulmonary sensitization. Chronic inhalation of Cr(VI) compounds (*e.g.* $CrO_4^{2-}$) increases the risk of lung, nasal, and sinus cancer.

**Mercury**

Mercury is a metal that is toxic to living organisms. It exists in several forms, some of which occur naturally in the environment.

Mercury vapor and alkyl mercury compounds are known to be very toxic. Alkyl mercury compounds can bind to functional groups in protein.

**Lead**

Lead is an element widely used in industries. The main sources of contamination: - toys, vessels used for storage and transport, agricultural products. The intake of lead from drinking water is also possible where domestic lead plumbing is used.