Chemistry of biogenic elements.

BIOGENIC ELEMENTS

All matter in the Universe occurs in the form of atoms of a small number of elements. There are 92 naturally occurring chemical elements in the Universe.

- Almost every one of the chemical elements plays some role in Earth's living systems, however, ≈20 elements account for the vast majority of material in living systems.

These ***biogenic elements are divided into:***

- six major biogenic elements (elements found in almost all of Earth's living systems, often in relatively large quantities);
- five minor biogenic elements (elements found in many of Earth's living systems, and/or in relatively small quantities);
- trace elements (essential elements necessary only in very small quantities to maintain the chemical reactions on which life depends, or elements found only a very few of Earth's living systems).

Major Biogenic Elements

Carbon
Hydrogen
Oxygen
Nitrogen
Sulfur
Phosphorous

Minor Biogenic Elements

- Sodium
- Potassium
- Magnesium
- Calcium
- Chlorine

Biogenic Trace Elements

- Manganese
- Iron
- Cobalt
- Copper
- Zinc
- Boron
- Aluminum
- Vanadium
- Molybdenum
- Iodine
- Silicon
- Nickel
- Bromine

According to their amount in the organism, biogenic elements can be classified into:

- Organically bound elements: 90 % human body.
- Macroelements (basic): 10 – 0,1%.
- Trace or microelements: 0,1 – 0,0001%.
- Contaminating elements (Ultra-trace or ultramicroelements): lest then 0,0001%.

Macroelements (12 elements in total) form up to 99 % of any organism, and can be further subdivided into:

- **a group of stable primary elements** (1-60 % of total organism weight**).** These are: **O,C, H,N**,
- **a group of stable secondary elements (0.05/1 %** of total organism weight**).** These are **Ca, S, Mg, Cl, Na, K, Fe**

Microelements can be divided into three categories:

- **a subgroup of 8 stable elements** (less than 0.05%). These are the elements: Cu, Zn, Mn, Co, B, Si, F, I
- **a subgroup of approximately 20 elements** that are present at conc. of 0.001% and lower.
- **a subgroup of contaminating elements**: Their constant excess in the organism leads to disease: Mn, He, Ar, Hg, Tl, Bi, Al, Cr, Cd.

According to their physiological importance, biogenic elements are essential and nonessential.

Essential elements can be divided into two groups:

- **main essential elements, such as Ca, Mg, Na, K, P, S, Cl** present in food. They usually play multiple roles.
- **trace essential elements**

The general function of minerals and trace elements can be summarized as follows:

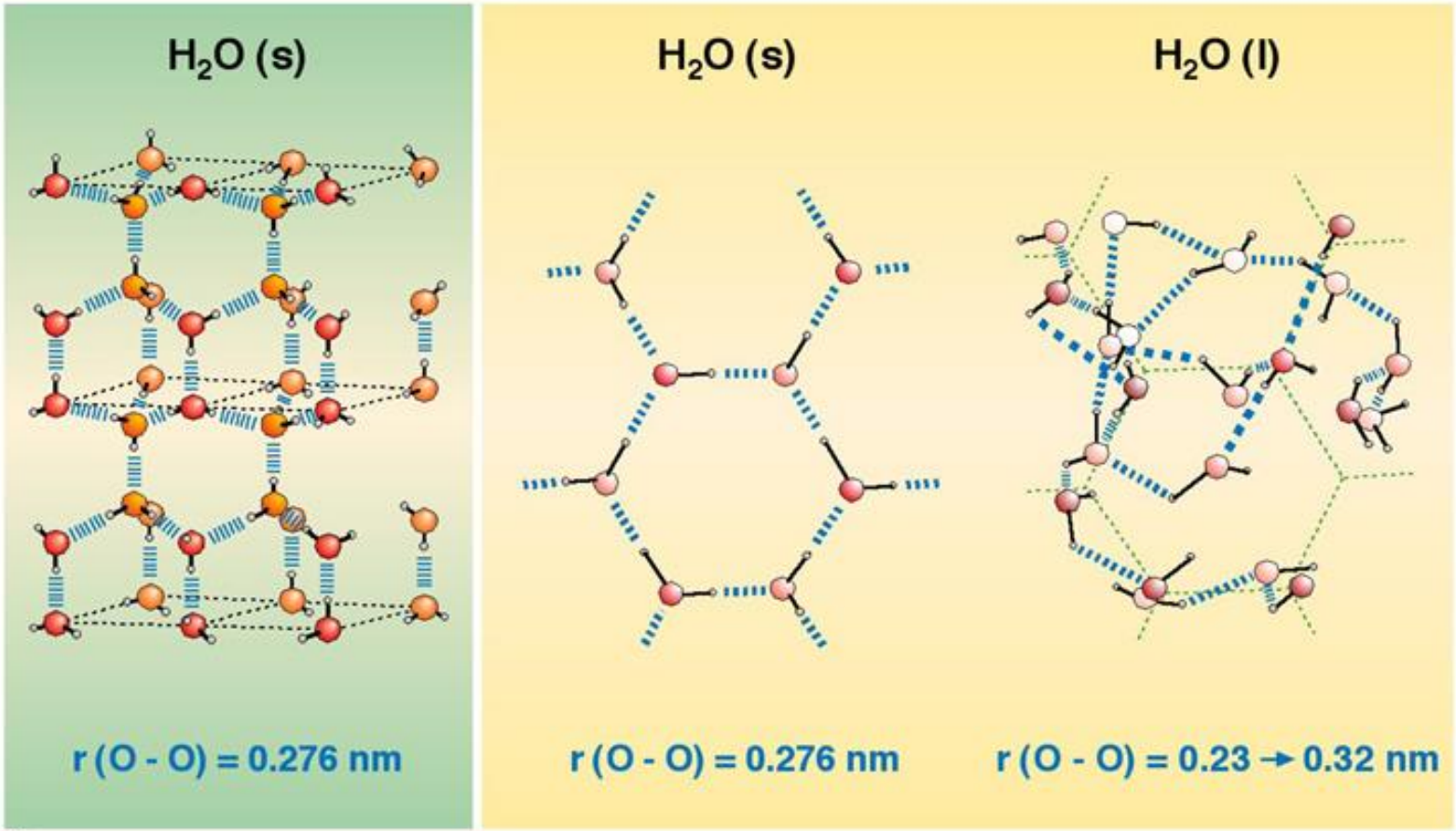
- Minerals are essential constituents of skeletal structures such as bones and teeth.
- Minerals play a key role in the maintenance of osmotic pressure, and thus regulate the exchange of water and solutes within the animal and human body.
- Minerals serve as structural constituents of soft tissues.
- Minerals are essential for the transmission of nerve impulses and muscle contraction.
- Minerals play a vital role in the acid-base equilibrium of the body, and thus regulate the pH of the blood and other body fluids.
- Minerals serve as essential components of many enzymes, vitamins, hormones, and respiratory pigments, or as cofactors in metabolism, catalysts and enzyme activators.

Organically bound elements (Organic element)

HYDROGEN

OXYGEN

Structure of water
Hydrogen and polar covalent bonds



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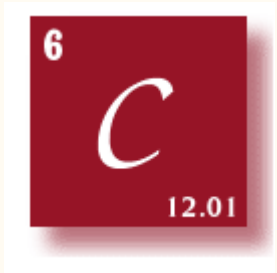
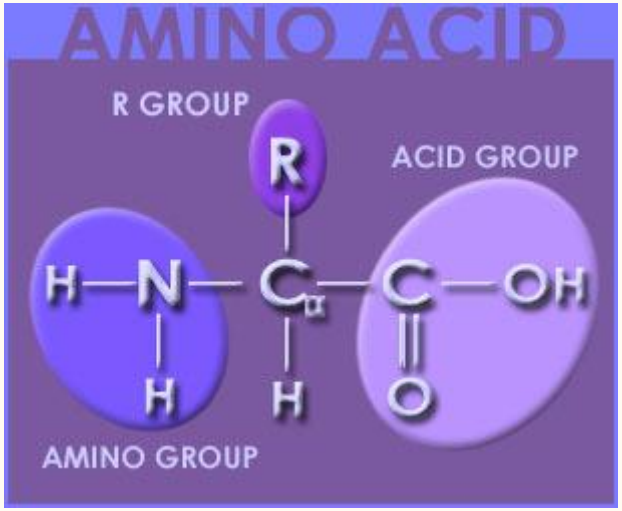


Carbon

- Carbon, although the second most abundant element in living organisms, accounts for only 0.02% of the mass of the earth's crust. It is present in carbonate minerals, such as $CaCO_3$ limestone and in fossil fuels, such as coal, petroleum, and natural gas. In uncombined form, carbon is found as diamond and graphite.

NITROGEN



- Inert diatomic (N_2) gas plentiful in the atmosphere (78%), very stable and unreactive. Nitrogen is an essential element for life, because it is a constituent of DNA for genetic coding and of amino acids making up proteins, some of which are catalytically active enzymes.

Macroelements

s-elements

Alkali metals are metals found in Group 1 of the periodic table : Li, Na, K, Rb, Cs, and Fr –have the smallest ionization energies of all the elements because of their valence-shell electron has ns^1 configurations.

Sodium

Sodium is the principle cation of the extracellular fluid.

Functions

1. Regulation of acid-base balance.
2. Maintenance of osmotic pressure of the body fluids.
3. Preservation of normal irritability of muscles and permeability of the cells.

The normal serum sodium level is 133-146 mEq/l.

Potassium

Potassium is the principal cation of the intracellular fluid.

Functions

1. Intracellular cation in acid-base balance.
2. In muscle contraction, particularly in cardiac muscle.
3. Conduction of nerve impulse.
4. Cell membrane function.

The normal concentration of potassium in the serum is 3.5–5.5 mEq /l.

The Alkaline Earth Metals (Group 2A)

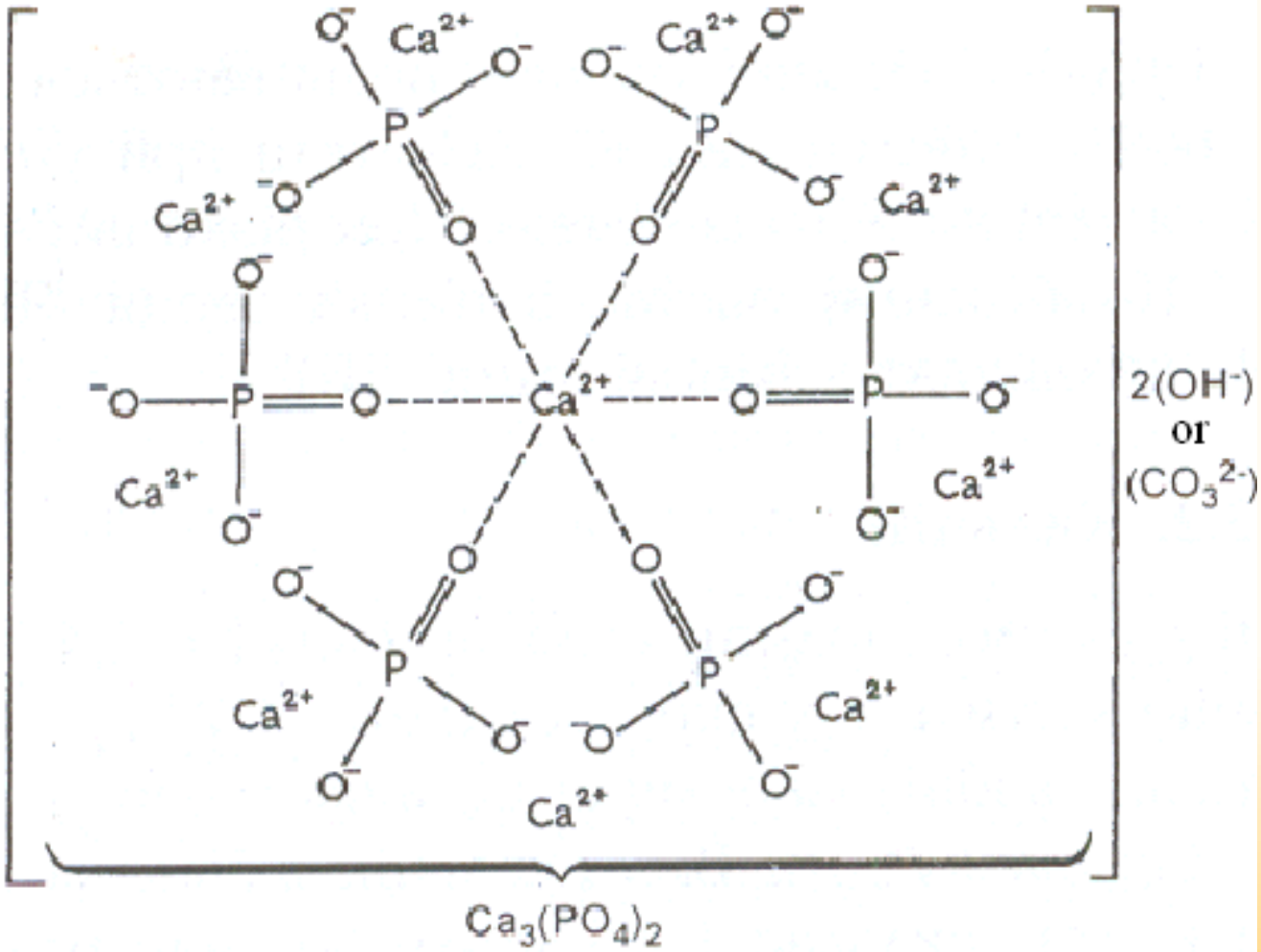
The alkaline earth elements in group 2A - Be, Mg, Ca, Sr, Ba, and Ra - are similar to the alkali metals in many respects. They differ, however, in that they have ns^2 valence-shell electron configurations and can therefore lose two electrons in redox reactions. Alkaline earth metals are thus powerful reducing agents and form ions with a +2 charge.

Calcium

Calcium is present in the body in the largest amount of all the minerals present in the body. Calcium comprises 2% of the body weight. RBC is devoid of calcium. The normal serum level is 9 – 11 mg percent.

Calcium is present in three forms:

1. Calcium present in ionic form, serving as an important regulator of processes in cell cytoplasm.
2. Protein bound fraction. (This form is physiologically inert.)
3. In combination with citrates. (Protein bound fraction is non-diffusible whereas other two fractions are diffusible.)

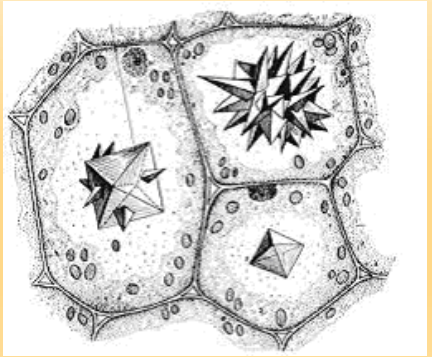


Structure of hydroxylapatite's

Calcium is present in bones in the form of hydroxyapatite: $(Ca_3(PO_4)_2)_2*Ca(OH)_2$

Functions of calcium

1. Calcium along with phosphorus is essential for bones and teeth formation.
2. In blood coagulation. Calcium activates the conversion of prothrombin to thrombin.
3. In enzyme activation. Calcium activates large number of enzymes such as adenosine triphosphatase (ATPase), succinic dehydrogenase, lipase etc.
5. In muscle contraction.
6. In normal transmission of nerve impulses.
7. In neuromuscular excitability.



Qualitative reaction:

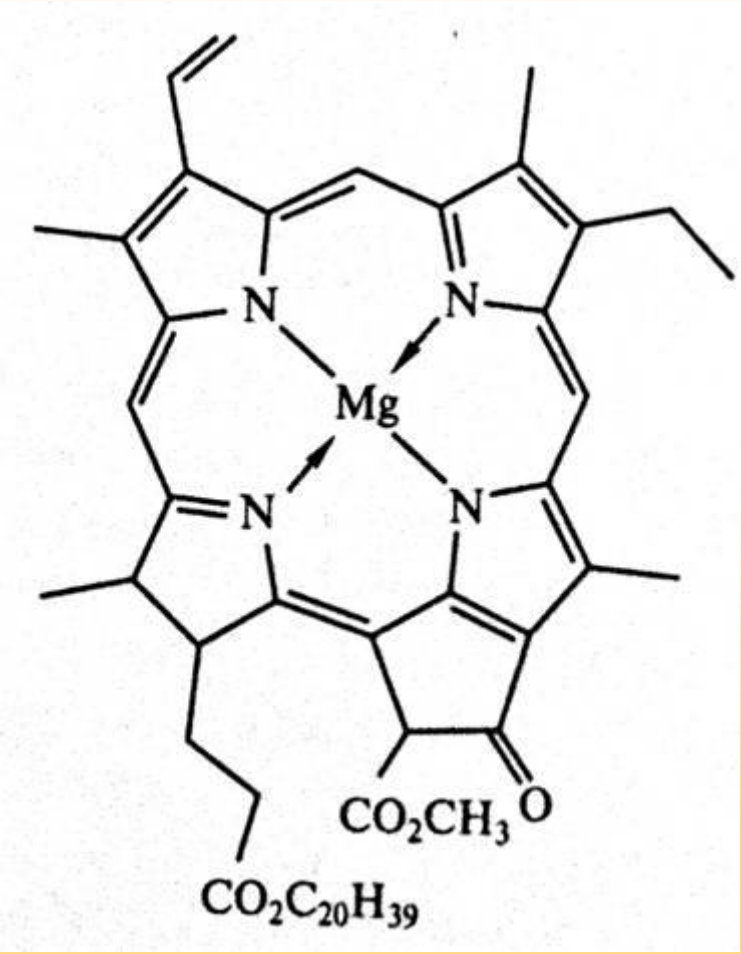
$CaCl_2+(NH_4)_2C_2O_4= 2NH_4Cl + CaC_2O_4$ (precipitate)

Magnesium

Biological function:

- Magnesium is an essential component of bone, cartilage and the crustacean exoskeleton.
- Magnesium is an activator of several key enzyme systems (enzymes that catalyse the transfer of the terminal phosphate of ATP to sugar or other acceptors).
- Through its role in enzyme activation, magnesium (like calcium) stimulates muscle and nerve irritability (contraction), is involved in the regulation of intracellular acid-base balance, and plays an important role in carbohydrate, protein and lipid metabolism.

Chlorophyll



Identification reaction on $\mathbf{Mg^{2+}}$:

$Mg^{2+} + OH^- \rightarrow Mg(OH)_2\downarrow$ – white amorphic sediment;

$Mg^{2+} + NH_4OH \leftrightarrow Mg(OH)_2\downarrow + NH_4^+$;

$MgCl_2 + NH_4OH + NaHPO_4 + 5H_2O \rightarrow MgNH_4PO_4 \bullet 6H_2O\downarrow + 2NaCl$ – white crystalline sediment;

Identification reaction on $\mathbf{Ca^{2+}}$

$CaCl_2 + (NH_4)_2CO_3 \rightarrow CaCO_3\downarrow + 2NH_4Cl$ – white amorphic sediment;

$Ca^{2+} + SO_4^{2-} \rightarrow CaSO_4\downarrow$;

$Ca^{2+} + C_2O_4^{2-} \rightarrow CaC_2O_4\downarrow$;

$K_4[Fe(CN)_6] + Ca^{2+} \rightarrow K_2Ca[Fe(CN)_6]$ – white sediment;

$Ca^{2+} + HPO_4^{2-} \rightarrow CaHPO_4$ – white sediment;

P-elements (macroelements)

Phosphorus

Functions

1. Phosphorus along with calcium is essential for bones and teeth
2. Buffering action, i.e., phosphate buffers.
3. In the formation of high energy compounds, i.e., ATP.
4. In the synthesis of RNA and DNA.
5. In the synthesis of phospholipids.
6. In the synthesis of phosphoproteins.

Phosphorus is present in the blood as:

1. Inorganic phosphorus.
2. Organic phosphorus.

The normal serum inorganic phosphorus level 2.5 – 4 mg percent.

It is higher in children, the value being 4 — 6 mg percent.

Sulfur

- Sulfur is present in three amino acids. Methionine, cystine and cysteine and thus it is present in all proteins in the body. Connective tissue, skin, hair and nails are especially rich in sulfur. Also thiamine and biotin (member of Vitamin B complex) and coenzyme A contain sulfur in these molecules.
- Diet which is adequate in protein meets the daily requirement of sulfur.

Iodine

Biological function:

- Iodine is an integral component of the thyroid hormones, thyroxine and tri-iodo-thyronine, and as such is essential for regulating the metabolic rate of all body processes.
- Iodine is readily absorbed from the gastro-intestinal tract and the surrounding water by fish and crustacea. Dietary availability and absorption is reduced in the presence of high dietary intakes of cobalt.

Fluoride

Functions

1. It gives strength to enamel tissues.

2. It prevents the bacterial action to the teeth.

3. Necessary for the health of teeth.

Fluoride ions inhibits all those enzymes which needs Mg also, i.e., inhibition of glycolysis reactions. On enolase, it has the maximum inhibition activity.

Addition of fluoride salts in water is known as fluoridation.

d-elements (microelements)

Iron

Total iron content in the body is 3.5 gm. 70 percent of this iron is present in hemoglobin.

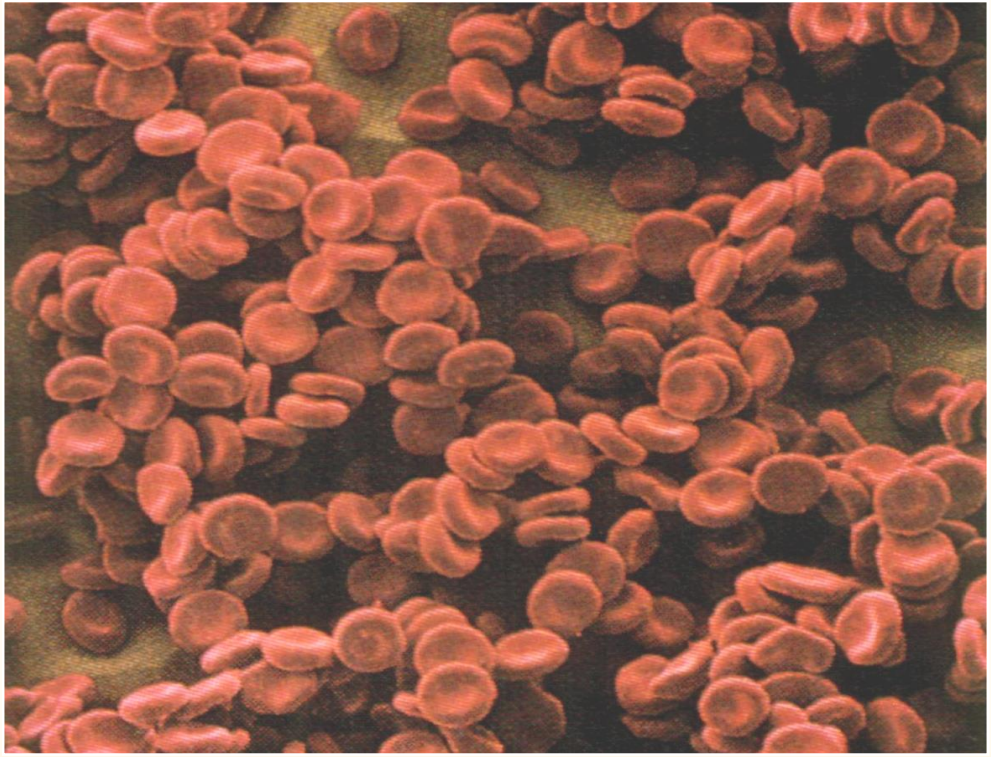
Biologically important compounds of iron are hemoglpbin, myoglobin, cytochromes, catalases, peroxidase. In all these compounds iron is present as heme form or porphyrin form. In addition to these iron is present in non-heme form called non-heme iron.

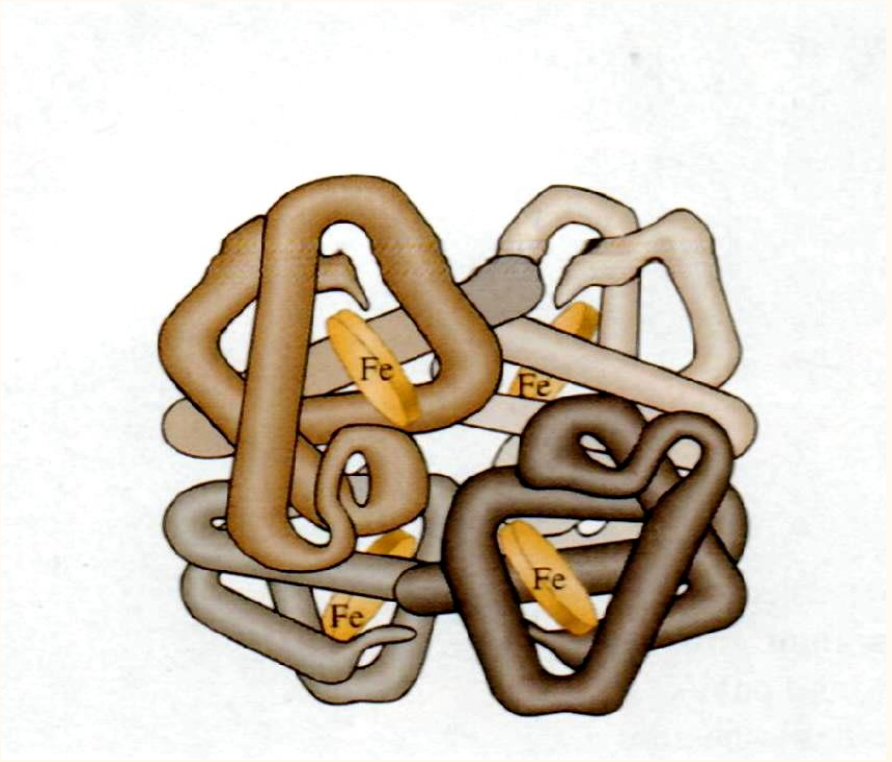
Non-heme iron is present as ferritin (a stored form of iron) and ransferring (a transport form of iron).

Functions of iron

1. As hemoglobin, in the transport of oxygen.

2. In cellular respiration, where it functions as essential component of enzymes involved in biological oxidation such as cytpchromes c, c_2 a etc.

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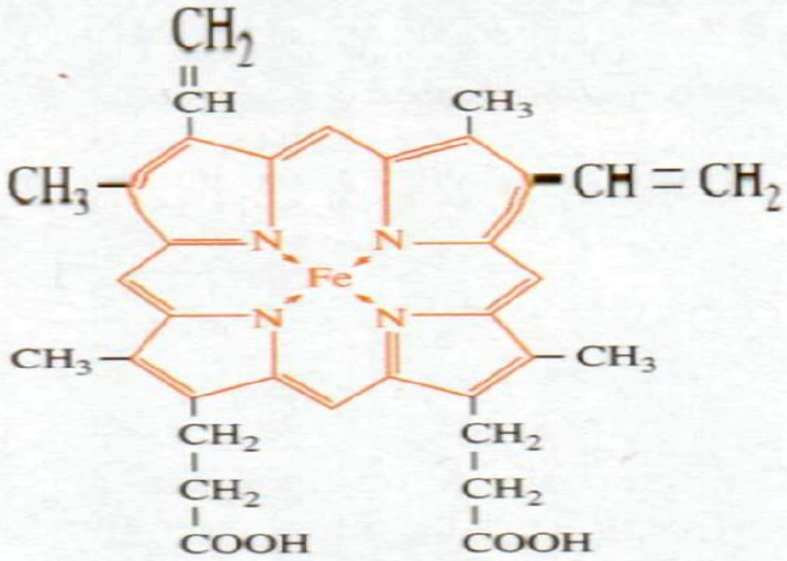
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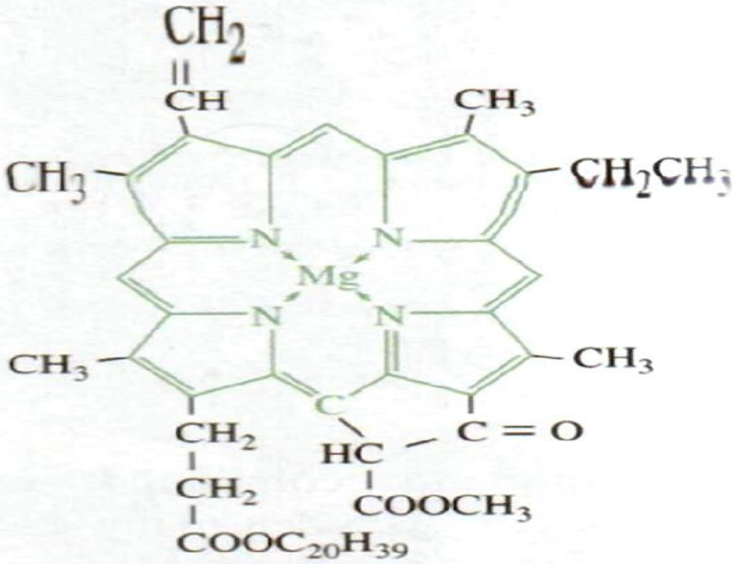
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COOCH3
COOC20H39

Copper

Total copper content in the human body is 100-150 mg. It is present in almost all the tissues of the body. Liver is the richest source of copper.

Functions

1. Copper is an important constituent of certain enzymes such as, cytochromes, cytochrome oxidase, cataiase, peroxidase, ascorbic acid oxidase, uricase, tyrosinase, cytosolic superoxide dimutase, etc.
2. Necessary for growth and bone formation.
3. Necessary for formation of myelin sheaths in the nervous systems.
4. Helps n the incorporation of iron in hemoglobin.
5. Helps in the absorption of iron from Gl tract.
6. Helps in the transfer of iron from tissues to the plasma.

Copper is present in the plasma as ceruloplasmin. The concentration of ceruloplasmin in plasma is 23 – 40 mg percent. The copper containing protein in RBC is erythrocuperin, in liver it is hepatocuperin, and in brain it is cerebrocuperin.

Zinc

Zinc is an important constituent of pancreas.

Functions

1. Zinc is a constituent of certain enzymes such as carbonic anhydrase, carboxypeptidase, alkaline phosphatase, lactate dehydrogenase, alcohol dehydrogenase, superoxide dimutase, retinene reducthse, DNA and RNA polymerase.
2. Necessary for taste buds.
3. Necessary for fertility of mice.
4. Necessary for tissue repair and wound healing.
5. Necessary for protein synthesis and digestion.
6. Necessary for optimum insulin action as zinc is the integral constituent of zinc.

Manganese

Biological function:

- Manganese functions in the body as an enzyme activator for those enzymes that mediate phosphate group transfer (ie. phosphate transferases and phosphate dehydrogenases), pyruvate carboxylase
- As a cofactor or component of several key enzyme systems, manganese is essential for bone formation (mucopolysaccharide synthesis), the regeneration of red blood cells, carbohydrate metabolism, and the reproductive cycle.

Cobalt

Biological function:

- Cobalt is an integral component of cyanocobalamin (vitamin B12), and as such is essential for red blood cell formation and the maintenance of nerve tissue.
- Although not confirmed, cobalt may also function as an activating agent for various enzyme systems.

Highly toxic elements !

- Hg, Cd, Cr, Arsenic (As), Lead (Pb)
- As all heavy metals, they accumulate throughout the food chain, affecting more strongly higher organisms, including man at the top of the food "pyramid"
- Mercury and Arsenic tend to appear in the nature quite spontaneously, originating from some anthropogenic (human) sources as well as from geologic formations and released by local chemical conditions.