ELEMENTS OF LIFE

By Philip E Gibbs

Abstract: Many of the elements in the periodic table plays a role in supporting life, either directly in biochemistry of indirectly in some supporting role. This is a catalogue of how each element is used.

1. HYDROGEN

Forms water with oxygen.

Hydrogen is one of the basic elements of organic chemistry and may be considered the second most important element for life. Present in all organic molecules where it forms a single bond with carbon enabling chain molecules to form. It is present in proteins, sugars, nucleic acids.

Hydrogen formed in the early universe and is the most abundant element today. It continues to be the main source of energy by fusion to helium in the Sun's core.

2. HELIUM

Chemically inert, but an important step in the abundant synthesis of elements because three helium nuclei can fuse to form carbon.

Helium nuclei also form alpha radiation e.g. from radon gas, so can be linked to genetic mutations. It is also responsible for decay of Uranium-238 and Thorium-232 which heat the Earth's core.

Helium is also the by-product in nuclear fusion in the Sun's core.

3. LITHIUM

Lithium is a rare element on Earth, which is convenient because in large quantities it is harmful.

In trace quantities it is through to be important for biological development especially for the young fetus.

It can be used as a mood stabiliser drug but should not be used while pregnant.

Lithium deficiency can cause mental illness.

4. BERYLLIUM

Beryllium is another rare light element that has little function for life.

Beryllium-8 has a very short half-life but its energy levels are tuned along with those of carbon-12 to allow synthesis through nuclear fusion of helium to form carbon-12.

Beryllium deficiency can cause weight loss and fatigue

5. Boron

Boron is essential for plants in small amounts to strengthen cell walls.

In animals it is essential in trace amounts for the metabolism of calcium used to form bones and teeth.

Boron deficiency causes osteoporosis.

6. Carbon

Carbon is the defining element of organic chemistry and the most important element for life. It's four covalent bonds allow it to form complex chain and branching molecules. It can form stable bonds with a variety of other elements including hydrogen, oxygen, nitrogen, phosphurus and sulphur which are important in nucleic acids and proteins. It can also form string double bonds.

Carbon reacts with oxygen to form carbon dioxide, an important molecule in the carbon cycle between plants and animals.

7. Nitrogen

Nitrogen is the fourth most important element for life after carbon, hydrogen and oxygen. It is a component of amino acids which are the building blocks of proteins. It is also present in urea and nucleic acids.

8. Oxygen

Oxygen is the third most important element for life. It is taken in from the atmosphere by animals to metabolise carbohydrates for energy. Plants produce oxygen from carbon dioxide by photosynthesise.

Oxygen forms water with hydrogen.

Oxygen is present in most organic compounds including all proteins.

As ozone in the upper atmosphere it also protects life from harmful ultraviolet radiation

9. Fluorine

Fluorine is used by some microorganisms and plants but is not essential for animals. However, fluorine does strengthen teeth and a deficiency can be a cause of dental decay.

10. Neon

The noble gas Neon is the fifth most abundant element in the universe, but because it is inert and rare on Earth it plays no role in biology.

11. Sodium

Sodium in salt is required in significant quantities in animals to ensure the right electrolyte balance. Too much or too little causes life-threatening problems so it is regulated in the blood by the kidneys.

Sodium is also important for the generation of nerve impulses.

The presence of sodium in animals may also be linked to its concentration in sea water where sea-life must keep an electrolyte balance with its environment.

12. Magnesium

Magnesium is an essential element in biological systems, being present in every cell. ATP, the source of energy in cells can only work when bound to a magnesium ion.

It stabilises all organic compounds that contain phosphate including RNA and DNA.

Magnesium has catalytic properties facilitating biochemical reactions in over 300 known enzymes.

Another important example in plants is that magnesium is necessary for synthesising chlorophyll.

Magnesium deficiency in animals can cause a wide range of severe symptoms.

13. Aluminium

Aluminium is one of the few reactive elements that does not play a significant role in biology. Although its abundance in the universe is low (0.005%), it is the third most common element in the Earth's crust after silicon and oxygen. It's primary role is therefore to help form the rocky substrate on which life can thrive.

14. Silicon

Silicon has been proposed as an alternative to carbon as a basis for life, but it is much less versatile in its chemical bonds with other elements. In fact it is considered to not be essential to life.

However, Silicon is the most abundant element in the Earth's crust after oxygen, and it is absorbed into plants. It is said to help growth to some extent.

In humans silicon deficiency may be responsible for some ailments but it is not known to serve a specific purpose.

The main use of silicon for life is to form the Earth's crust on which life can live.

15. PHOSPHORUS

Phosphorus is the fifth most important element in biochemistry. It is crucial in RNA, DNA and especially ATP.

It has been speculated that arsenic could potentially replace the role of phosphorus in primitive life but this has never been demonstrated.

16. SULPHUR

Sulphur is the sixth and last in the list of essential elements for the basics of life as we know it.

Sulphur is a component of the amino acids cysteine and methionine.

Sulphur deficiency causes physical deformities and mental retardation and can be fatal.

17. CHLORINE

Chlorine combined with sodium forms common salt which is important for electrolyte balance in the body.

As a constituent in hydrochloric acid, it is important for digestion.

18. ARGON

As a rare noble gas argon is not used in biology

19. POTASSIUM

Potassium is the main intracellular ion for all types of cells. It complements sodium in providing electrolyte balance.

Potassium is important in neurotransmission, muscle contraction and heart function. Deficiency increases risk of hypertension, stroke and cardiovascular disease.

Radioactive decay of Potassium-40 was the main contributor to heating the earth's core in its early history.

20. CALCIUM

Calcium is well known in biology for forming bones and teeth, however it has many other important roles.

Calcium ions are important in signal transduction pathways for muscle contraction and fertilization.

It is a cofactor of many enzymes, especially for blood-clotting.

21. Scandium

Although Scandium is not especially rare in the earth's crust it has very little impact on biology. It is not used in any biochemical process and is not toxic in normal quantities.

22. Titanium

Most living species appear to have no use for titanium but there are sea squirts that filter it into their bloodstream.

Titanium oxide can convert sunlight into energy so may be used in some bacteria as an alternative to chlorophyll. Perhaps it was more significant in very early life forms.

23. Vanadium

Vanadium is used in some marine species in particular.

Some bacteria use it for fixing nitrogen (an alternative to molybdenum)

Vanadium is also essential in ascidians and tunicates but its exact purpose in unclear.

In mammals Vanadium may promote growth.

24. Chromium

Chromium is believed to be essential in the body for insulin, sugar and lipid metabolism, but its necessity is debated.

25. Manganese

Manganese is an important element for human health, essential for development, metabolism, and the antioxidant system.

26. Iron

The most important role for iron is as the active component in haemoglobin for carrying oxygen in the blood.

Iron is also used in redox enzymes.

A non-biological role of iron that is important for life is in forming the Earth's molten core where it is responsible for the magnetic field that protects us and our atmosphere from the effects of the solar wind.

27. Cobalt

Colbalt is essential for the metabolism of all animals. It is a key element in vitamin B12.

28. Nickel

Nickel is known to play an important role in the biology of some plants, eubacteria, archaebacteria, and fungi.

Nickel released from Siberian Traps volcanic eruptions is suspected of assisting the growth of Methanosarcina, a genus of euryarchaeote archaea that produced methane during the Permian–Triassic extinction event 250 million years ago.

29. Copper

Copper is a component of proteins involved in oxygen transportation. Their use began when algae produced oxygen in the atmosphere long before iron became the dominant means of oxygen transport in animals. Its role is still essential at the cellular and sub-cellular level.

30. Zinc

Zinc is the only metal that appears in all enzyme classes and is the second most transition element in organisms.

In the brain, zinc is stored in specific synaptic vesicles by glutamatergic neurons and can modulate neuronal excitability.

It plays numerous other roles.

31. Gallium

Gallium has no known natural role in biology.

32. Germanium

Germanium is not considered essential to the health of plants or animals.

33. Arsenic

Some species of bacteria obtain their energy by oxidizing various fuels while reducing arsenate to arsenite.

34. Selenium

Selenium is a component of the unusual amino acids selenocysteine and selenomethionine.

35. Bromine

Bromine is adundant in the sea and compounds play a role in the function of many sea algae.

38. Strontium

Acantharea, a relatively large group of marine radiolarian protozoa, produce intricate mineral skeletons composed of strontium sulfate

42. Molybdenum

Molybdenum is an active element in enzymes that fix nitrogen forming ammonia. This is done by certain bacteria and then reused by plants and animals. A scarcity of molybdenum in the early oceans may have been a factor in limiting evolution for the first 2 billion years of the Earth's history.

53. Iodine

Iodine is the heaviest element that is essential for life. It is a constituent of thyroid hormones.

Iodine deficiency is a significant cause of mental retardation.

74. Tungsten

Tungsten is the heaviest element which appears in biochemistry being a component of a few bacterial enzymes.

80. Mercury

Despite its high toxicity. Mercury is used by purple non-sulfur bacteria as an electron acceptor in an alternative primitive form of photosynthesis.

90. Thorium

Decay of Thorium-232 heats the Earth's core (see Uranium)

92. Uranium

The decay of Uranium-238 is one of the principle sources of heat in the Earth's core today (along with Thorium-232). Uranium-235 was a heat source in the early Earth. This keeps the Earth's core molten enabling a magnetic field to persist, protecting the planet and its atmosphere from solar wind. It also provides volcanic and tectonic activity.

Uranium is the heaviest naturally occurring element.

SUMMARY

In the first four periods of the periodic table, all alkali metals, alkaline earth metals, halogens and other non-metals, and most transition metals play a biological role. Classes of elements that do not appear to be essential for any form of life are noble gases, metalloids, post-transition metals and group three transition metals. This means that only ten of the first 36 elements are not used in biochemistry, namely Helium, Beryllium, Neon, Aluminium, Silicon, Argon, Scandium, Gallium, Germanium and Krypton

In the higher periods Strontium, Molybdenum, Iodine, Tungsten and Mercury play a role in some life forms. In all 31 naturally occurring elements are known to appear in biochemistry.

Other elements are important to life in other ways e.g. by providing nuclear energy that heats the Earth's core (Thorium and Uranium) or as mineral substrate (Aluminium and Silicon). Helium is especially relevant to stellar nucleosynthesis and radioactivity.