Opening Address

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The Evolution of the Usage of Chemical Elements by Biological Systems

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Comparative analysis of the elemental composition of remnants of primitive anaerobic prokaryotes and modern aerobic eukaryote species shows that there have been considerable changes in element contents and their distribution in cell's compartments as well as in their utilisation, although several chemical processes in cells have remained almost unaltered to this day. To understand such changes one must take into account the modifications which have occurred in the atmosphere, in the sea and on the surface of the Earth since life emerged on our planet some 3.8 billion years ago.

Initially containing reduced gases such as CH_4, NH_3, H_2O, H_2S, H_2Se and even H_2, as well as the more oxidised CO, CO_2 and N_2, the atmosphere evolved and reached its present composition in which N_2 and O_2 are overwhelmingly dominant. In the same period the sea evolved from a very low redox potential, about –0.5 to 0.0 volts at low pH(HCl), to the present +0.8volts at pH~8, while dissolved sulfide, originally at a rather high saturation concentration (perhaps 0.1M), was oxidised to sulfate. This led to a dramatic increase in the availability of various metal elements, e.g. Zn, Cu and Cd, and to a decrease in the availability of others, especially Fe, whose free ionic concentration (of Fe^{3+}) went down to 10^{-18} due to the insolubility of its hydroxide. Dioxygen and other oxidised species, on the other hand, became widely available.

The Earth's crust also changed; many sulfides initially present were also oxidised and oxides became dominant. The pH of the sea and other Earth waters increased slowly due to the leaching of these basic rocks by strongly acid rain, and Ca was largely precipitated as carbonate.

The question that arises is: Did these changes affect the development of life on Earth? In which ways? In this lecture we will explore this question and will argue that environmental changes, associated to induced changes in DNA, were (and are) a major cause of evolution of living species, and not random mutations which can only be deleterious to well-adapted organisms. Furthermore, the majority of the mechanisms of appropriation of the required elements and rejection of the unwanted ones are directly or indirectly linked to element-dependent mechanisms of regulation of constitutive or induced protein synthesis, which provide the necessary link between the organisms' cells and their environment. Survival of the fittest, therefore, is primarily a matter of physical and chemical adaptation to a given environment, and only after that come the strategies of reproduction and competition for the same resources.

To support this view, we contend that stable (fit) organisms have a stable chemistry based on a given set of elements, so that any new element that becomes available in the environment is initially treated as an unwanted poison to be neutralised or rejected, but if it becomes permanent it may happen that it comes to be used as a signalling device, then as a messenger and finally as a further essential element, a codified required new partner in a novel, stabilised chemical system. A novel species arises which is represented by a slightly modified DNA, but in which the previous chemistry is largely preserved. Evolution is by addition, not by substitution. The cases of dioxygen, calcium, zinc and copper will be used as examples.

The arguments concerning this 'natural' evolution caused by a 'natural' selection of available chemical elements can be extended to the 'purposeful' evolution in the usage of chemical elements by a particular organism – man. It is still a 'natural' evolution since man, the human species, is just that – another evolved biological species.

Man has learned how to use a far more extensive range of chemical elements (all the naturally extent and some he himself has made) in a far more extensive range of conditions. Given the previous evolution history, which are the foreseeable consequences?

References

The question of the selection and use of chemical elements by biological systems has been discussed at length in the following books and review:

[1] Fraústo da Silva, J.J.R.; Williams, R.J.P. (1991, reprinted 1997): The biological chemistry of the elements – the inorganic chemistry of life. Oxford University Press, Oxford
[2] Williams, R.J.P.; Fraústo da Silva, J.J.R (1996, reprinted 1997): The biological selection of the chemical elements – the environment and life's chemistry. Oxford University Press, Oxford
[3] Williams, R.J.P.; Fraústo da Silva, J.J.R (1999): Bringing chemistry to life – from matter to man. Oxford University Press, Oxford
[4] Williams, R.J.P.; Fraústo da Silva, J.J.R (2000): The distribution of elements in cells. Coordination Chemistry Reviews