ANTIMONY AND BISMUTH MAY BE SUBSTITUTED FOR PHOSPHOROUS ATOMS IN DNA

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In 1953 F. Crick J. D. Watson and M. Wilkins for the first time described the structure of DNA molecule. It has been so far believed that bonds between nucleotides in the DNA chain are formed by deoxyribose and phosphate group. However, this postulate was reconsidered in December 2010, when Felisa Wolfe-Simon (NASA Astrobiology Research Center) reported the discovery of a bacteria GFAJ-1 (genus *Halomonadaceae*), in the DNA of which arsenic atoms may be substituted for phosphorous under certain conditions [1, 2].

On the whole, the idea about the existence of such organisms could have been quite obvious, because both elements (phosphorous and arsenic) belong to the same subgroup of the periodic system and thus, their physical and chemical properties are quite similar. However, although the idea itself may appear to be quite simple, the possibility of existence of the organisms, whose genetic material is built on the basis of arsenic, was not suggested till the discovery of this bacterium.

In April 2012 the Science journal published an article, which reported that the researchers from the MRC Laboratory of Molecular Biology (Cambridge) synthesized the alternative DNA and RNA molecules, in which the ribose and deoxyribose residues were substituted, and six alternative genetic polymers, which were called XNA, were obtained.

It was shown that XNA may form double helix similarly to DNA, and this structure may be more stable in comparison with natural genetic material, when performing its main function of information encoding [3].

In July 27, 2012 an article was published in Science journal, which described the results of DNA analysis of GFAJ-1. First, it was suggested that the bacterium substitutes the arsenic for phosphorous in its DNA in case of phosphorous deficiency in the environment. Nevertheless, the chemical structure of DNA of GFAJ-1 was shown to be quite normal and built on the basis of phosphorous rather than arsenic. Mass-spectrometric analysis revealed that arsenic is present in DNA of GFAJ-1 in free form, i.e. it is not bound to other atoms of nucleic acid by covalent bonds. In other words, arsenic may be present in bacteria, but it is not involved in the structure of vitally important molecules. The second paper, which disclaimed “the HACA science fiction”, was published by the group of scientists from the Institute of Microbiology, The Higher Technical

School of Zurich (Switzerland). The scientists showed that bacteria use phosphorous to build their DNA even under phosphorous deficiency conditions and abundance of arsenic. If concentration of phosphorous decreases too much, so that its falls lower the critical value, the bacteria cease growing and arsenic cannot reconstitute their growth. It is true that some organic molecules, which contain arsenic atoms in their structure, may be found in bacterial cells. However, it was shown that these molecules were formed abiotic manner, i.e. without bacterial enzymes, and none of them is involved in metabolism of bacterial cell [8].

Nevertheless, in the present article, we decided to take the risk to hypothesize that such elements, as arsenic, antimony and bismuth may also work as the basis of life (nucleic acids) in some still unknown organisms. It was already mentioned that all these elements belong to the major subgroup of the fifth group of the periodic system. Therefore, like phosphorous, these elements can form the top oxides and hydrogen compositions with general formulas R_2O_5 and RH_3 respectively. It is common knowledge that the metallic properties of the elements increase from the top to the bottom of the group, because of increase in their atomic radii (P 1.34 Å, Sb 1.61 Å, Bi 1.82 Å). However, both antimony and bismuth are obviously nonmetal elements (by their physical properties: they are not forgeable; they do not conduct the electric current; by chemical properties: their hydroxides are characterized by acidic properties and they form salts with metal ions – antimonates and bismuthates, respectively). The anions of the phosphorous, antimonous and bismuthic acids are described by general formula EO_4^{3-}, in which E corresponds to P, Sb or Bi. All of them have tetrahedral structure.

Therefore, synthesis of complex organic compositions (Fig. 2) on the basis of more simple inorganic substances (Fig. 1) is doubtlessly possible.

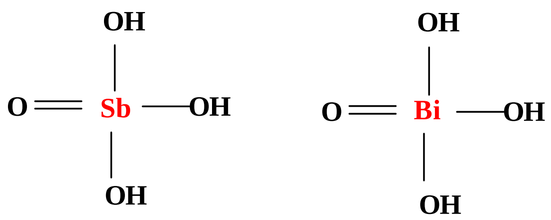

Fig. 1 Chemical structures of antimonous and bismuthic acids

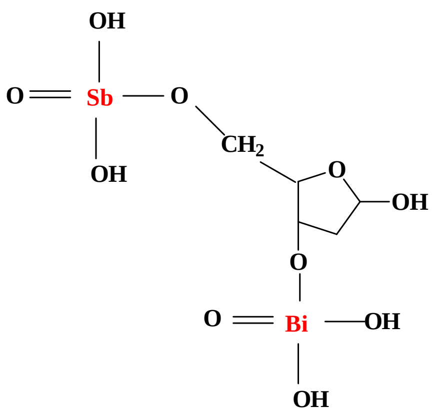

Fig. 2 Hypothetic example of antimony- and bismuth-containing glycoside

DNA built on the basis of As, Sb or Bi rather than phosphorous has been neither synthesized by anyone nor found in natural resources so far. However, it is believed that the three-dimensional structure built on the basis of antimony- or bismuth-containing carbohydrates may exist in accordance with its physical and chemical properties (Fig. 3).

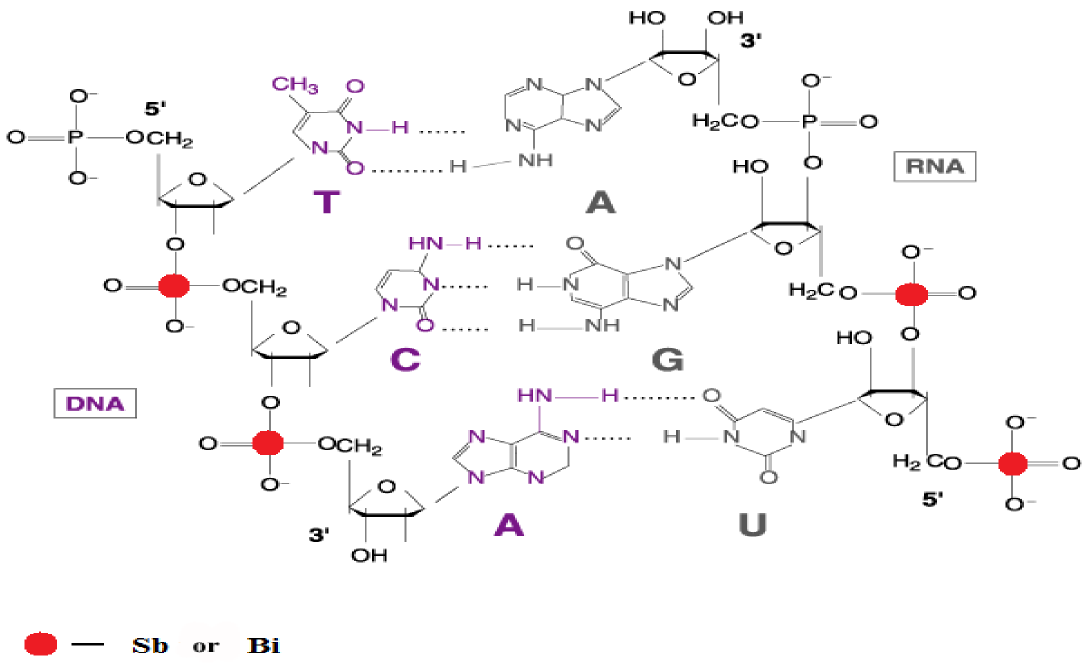

Fig. 3 Sites in the hypothetic XNA molecule, in which substitution of bismuth and antimony atoms for phosphorous takes place.

This hypothesis is supported by the analysis of the situation with amino acids, which contain elements of the major subgroup of the neighbor group VI of the periodic system. For example, oxygen- and sulfur-containing amino acids are well known. However, selenium-containing amino acids were first synthesized in 1930s, and found in living organisms in 1950s. For example, a minor amino acid, selenocysteine, is involved into the active center of glutathione peroxidase. It is also included into the structure of selenoproteins, deiodases and some other proteins. In mRNA, the selenocysteine is encoded by UGA nonsense codon on account that it is followed by a special stimulating nucleotide sequence [4, 5].

Moreover, Harkesh B. Singh (Indian Institute of Technology, Mumbai, India), who is a well acknowledged specialist in the chemistry of selenium- and tellurium-containing organic compositions, suggests that tellurium-containing amino-acids may be found in living organisms as well.

Based on aforesaid we suggest that living organisms, whose genetic material (DNA and RNA) would be built on the basis of arsenic, antimony and bismuth, may be found in the near future. Artificial synthesis of these compositions widens the definition of “life” itself.

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