

Arsenic and Life

Recent news about the research into *gammaproteobacteria* by Felisa Wolfe-Simon has caused quite a stir among astrobiologists and ordinary biologists as well. These bacteria were gathered from Mono Lake, California and in the laboratory were shown to be able to sustain life using arsenic in place of phosphorous in their diet. This includes polynucleotide backbones in both DNA and RNA and the biochemical energy currency ATP. It must also include all the pyrophosphate based coenzymes, e.g. (NAD⁺/NADH) and (FAD/FADH₂), and all the phospholipids!!

Arsenic, **As**, is also known to be a strong poison, a killer of life. This is often caused by inhibition of lipoic acid containing enzymes, e.g. pyruvate dehydrogenase and isocitrate dehydrogenase. The **As** competitively binds the lipoic acids thio groups and prevents the redox cycling between oxidation states of the thiols needed for normal energy metabolism, what biochemists call aerobic respiration. **As** also attacks other enzymes with thio groups in their active sites, usually as a cysteine residue. That **As** can fill this role is caused by its place in the [periodic table](#) just below phosphorous, **P**. **P**, in turn is just below nitrogen, **N**. Elements with this sort of relative vertical displacement in the periodic table have similar outer shell electron configurations and consequently similar chemistries *modulo* atomic size effects. The atomic radius of **As** is larger than that of **P** by 15%. The immediate neighbors to **P** and **As** in the periodic table, **S** (sulfur) and **Se** (selenium), have similarly related properties. **Se** can be very toxic and at the same time is an essential component of several enzymes that contain in their active sites selenocysteine, in which **Se** replaces **S**, a selenol rather than a thiol. Maybe there are also organisms in which **Se** replaces **S** on a bigger scale or even totally, in parallel with **As** and **P** in *gammaproteobacteria*. (I personally doubt total replacement is extant anywhere today.)

Clearly, in the *gammaproteobacteria*, resistance to attack by **As** of lipoic acid containing enzymes must have evolved to enable these microbes to survive where **P** is very rare and only **As** is available. Where **P** is available it is better suited for biochemical life than is **As** as is clear from observation of the results of

evolution. So I do not think we are dealing with putatively primitive life form or with an extraterrestrial life form based on different chemical rules. The mechanisms of stellar nucleosynthesis everywhere in the universe produce elements with abundance distributions favoring **P** over **As** by more than 3 orders of magnitude. Where **P** is suitable for the functions it serves, it is tried out geophysically and evolutionarily before **As** by dint of relative abundance. This is also true for the relative abundances of **S** and **Se**, favoring **S** by more than 3 orders of magnitude. Nevertheless, eventually evolution added **Se** to the roster of essential atoms of life in selenocysteine containing enzymes that work better than their **S** counterparts even in environments where **Se** is scarce and **S** is not.

The recent work of Wolfe-Simon is exciting, as biochemical discoveries often are, and it should be viewed as a variation on a standard theme rather than as a new paradigm.

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