**Could Lethal Arsenic be a Quintessential Part of DNA?**

Arsenic isn’t something you would like to eat. It is considered to be one of the deadliest poisons on Earth. It has a bad reputation as it contaminates the drinking water of millions of people. It almost acts as antagonistic to life as a chemical.

However, Felisa Wolfe-Simon surprises the entire world with a provocative finding: strange bacteria in the Mono Lake, California that thrived on something completely unexpected – arsenic. Measurements on arsenic DNA analogs made by researchers revealed that the arsenic analogs differed in stability from their phosphate versions by a mind-boggling factor of 1017. Reasonably it suggested that a different kind of life could possibly exist on some other planet.

The story began when scientists led by Felisa Wolfe-Simon of NASA’s Astrobiology Institute published a paper that articulated that the bacteria, found at Mono Lake (known for its high arsenic levels) in eastern California, could grow by replacing arsenic for phosphorus.

Their paper raised eyebrows because phosphorus was believed to be essential for life, while arsenic being chemically similar is a poison. If the bacteria can break rules like this, some argued, who knows what kinds of life may be possible beyond Earth?

Of the numerous elements in universe, life is mostly made up of just six: carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus. This elite clique is entailed to be omnipresent and irreplaceable. But the Mono Lake bacteria may have broken their dependence on phosphorus by substituting it for arsenic.

If this was true, they would be the only known living organism to do so. The discovery is amazing and it would imply that “Mono Lake was home to a form of life biologically distinct from all other known life on Earth” and “strongly suggests that life got started on our planet not once, but at least twice”.

**GFAJ-1: An Arsenic Lover**

Mono Lake lies in a sealed basin close to California’s Yosemite National Park. With no outlet connecting it to other bodies of water, any chemicals streamlined into the lake tend to stay there. As a result, the lake has fortified some of the highest concentrations of arsenic on the planet. To survive there, bacteria have to contend with the poison.

The bacteria, called GFAJ-1, a member of the genus Halomonadaceae, live in Mono Lake, amidst concentrations of arsenic that would kill most other life forms. During a 2010 NASA news conference, Felisa Wolfe-Simon announced GFAJ-1 was incorporating arsenate (a form of arsenic) into its DNA in place of phosphate. Earlier, Ronald Oremland discovered bacteria in Mono Lake that can fuel themselves on arsenic.

Wolfe-Simon is further establishing that the bacteria are incorporating arsenic into their most significant molecules of life. She had collected sediment from Mono Lake and cultured it on Petri dishes, provided a soup of vitamins and other nutrients, but without any trace of phosphorus. She took samples from these dishes and cultured them to fresh ones, gradually diluting them to get rid of any phosphorus that might have packed onboard. She kept on adding more and more arsenic throughout the experiment.

Astonishingly, bacteria still grew in the dishes. She isolated one of these arsenic-lovers, a strain called GFAJ-1. Using a sensitive technique called ICP-MS she demonstrated that these bacteria did indeed contain large amounts of ubiquitous arsenic. Wolfe-Simon exposed bacteria with a mildly radioactive arsenic to track its pathway and surprisingly she detected arsenic everywhere. Arsenic could able to successfully replace phosphorous to become an essential element of bacteria’s proteins and fats. Most importantly, it was integrated into...
ATP and even in their DNA. These results were confirmed from a number of other techniques.

Today, all other life employs phosphorus to make the backbone of the universal double helix, but GFAJ-1’s DNA had a rachis of arsenic. Wolfe-Simon noticed that bacteria became 50% larger if they were allowed to grow on arsenic compared to phosphorus, and they evolved a large internal compartment called vacuoles.

These might be the key to their survival. Wolfe-Simon thinks that the vacuoles could act as a safe garden for unstable arsenic-based molecules they might contain, chemicals that steady the molecules, and they might exclude water that would accelerate their breakdown. It’s an awesome result, yet there is a question to be asked. Wolfe-Simon still found an iota of phosphorus in the bacteria by the end of her experiment. The level of phosphorus was so low that the bacteria had no option to grow but it’s still not clear how important this phosphorus element is. Could the bacteria have literally been able to come through if there was no phosphorus at all?

Can Arsenic Bind to DNA?

In 1987, the eminent physical organic chemist Frank Westheimer published an article entitled “Why Nature chose Phosphates”. He addressed all aspects of phosphorus for being mostly chosen. However, in this publication, he considers other potential elements that might imaginably accomplish a similar function to phosphate, its esters, and anhydrides.

One of these is arsenate, which is indeed an attractive alternative due to the similarity of its basic structure as a tribasic acid capable of forming esters and anhydrides and almost identical pKa values. The original trademark of phosphate chemistry is the enormous hydrolytic stability of phosphodiesters which is an important cornerstone for DNA stability.

Chemists therefore wondered when Wolfe-Simon claimed what was considered to be evidence that a bacterium from the arsenic-rich Mono Lake in California, Halomonas strain GFAJ-1, could grow in the absence of phosphate and instead use arsenate.

How Stable is the Arsenic-substituted DNA?

To understand the stability of arsenic substituted DNA, researchers considered five types of phosphate binding protein (PBP) which bind phosphate in a biochemical pathway that contributes the cells from four species of bacteria. However two of the bacterial species were resistant to arsenate and two were sensitive to it.

To decipher how effectively these proteins discriminate between phosphate and arsenate, the researchers placed them in solution with a defined amount of phosphate and different concentrations of arsenate for 24 hours, and then assured which of the molecules the proteins would bind to. In the solutions containing 500-fold more arsenate than phosphate, all five proteins were still able to preferentially bind phosphate. It was only one protein, from the Mono Lake bacterium, that could do so at arsenate excesses of up to 4,500-fold over phosphate. It shows that this bacterium has evolved to extract phosphate under almost all circumstances.

The exceedingly high preference for phosphorus found in the key proteins in that species represents “the last nail in the coffin” of the hypothesis that GFAJ-1 uses arsenic in its DNA.

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