Modern-day metabolism could have originated in 4-billion-year-old oceans

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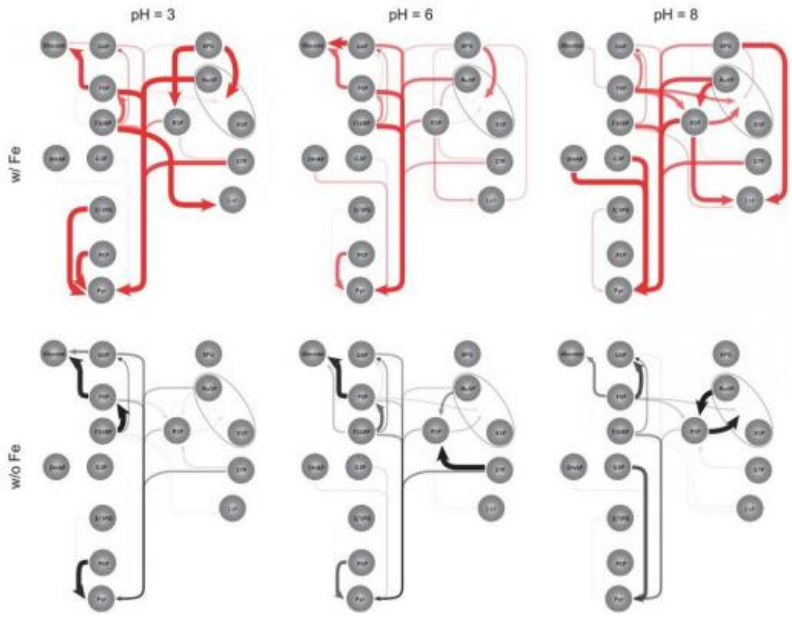

Scientists constructed this metabolism-like chemical network from non-enzymatic reactions that could have occurred in Earth's 4-billion-year-old oceans. The network shows that the reaction types depend on pH and the reaction rates depend on iron concentration (arrow thickness and red color intensity indicate the relative acceleration). Credit: Keller, et al. *Science Advances*

(Phys.org)—A gigantic number of chemical reactions take place inside our bodies every second, all synchronizing with each other to produce the energy and chemical compounds that we need to survive. Together

these reactions make up our metabolism, which is one of the defining features of life. However, scientists continue to debate the origins of metabolism: Did this complex arrangement of reactions evolve over time in living things due to survival advantages, or was it acquired, in a basic form, from the non-living environment?

In a new study, researchers have found that some of the metabolic processes (glycolysis and the pentose phosphate pathway) that convert sugars into energy and molecular building blocks share many similarities with the chemical reactions that could have occurred in non-living four-billion-year-old Archean oceanic sediments. The results suggest that the metabolic reactions in our modern-day cells could, in principle, have originated from chemical reactions in an environment that preceded life.

The researchers, Markus A. Keller and Markus Ralser from the University of Cambridge and coauthors, have published their paper on the ancient metabolism-like reactions in a recent issue of *Science Advances*.

The work builds on a paper published by some of the same authors in 2014, in which they recreated environments similar to Earth's ancient oceans in the lab and observed chemical reactions that formed glucose, pyruvate (a product of glycolysis), and precursors of modern-day nucleic acids and amino acids, in a similar way that living organisms do today.

One of the most striking things about the results from that paper was that the ancient sediments enabled the reactions without containing enzymes, since enzymes came into existence during the evolution of modern organisms. Enzymes are proteins that speed up metabolic reactions, and living things greatly depend on them to catalyze their metabolism. Without enzymes, metabolic reactions would occur too slowly for life as we know it to exist.

Although these ancient sediments lacked enzymes, they did contain large amounts of iron, and the researchers showed in the 2014 study that iron can act as a catalyst in place of enzymes. It's widely thought that iron existed in much higher concentrations in the ancient oceans than in modern oceans because the ancient oceans did not contain any oxygen, and this condition enabled large quantities of iron to dissolve.

In the new paper, the researchers have shown that these 4-billion-year-old iron-catalyzed reactions can not only produce some of the essential chemicals of metabolism, but like metabolism, they also have the ability to switch biochemical pathways on and off. This ability enables modern cells to react to changes in the environment.

By performing more than 4000 highly sensitive mass spectrometry and nuclear magnetic resonance experiments, the researchers found, for example, that neutral-pH conditions favor glycolysis, while alkaline-pH conditions favor the pentose phosphate pathway. This finding suggests that relatively moderate changes in the environment could have led to changes in metabolism.

In addition, the researchers observed that the presence of iron accelerates the reaction rates over most of the pH range, with some reactions exhibiting a 100-fold rate increase. These examples of conditional reactivity provide a method of regulating the reactions, which is an essential feature of metabolism.

Overall, the similarities demonstrate that modern-day metabolism could have originated from pre-enzymatic iron-catalyzed chemistry—but whether it actually did or not remains an open question.

More information: Markus A. Keller, et al. "Conditional iron and pH-dependent activity of a non-enzymatic glycolysis and pentose phosphate pathway." *Science Advances*. DOI: 10.1126/sciadv.1501235