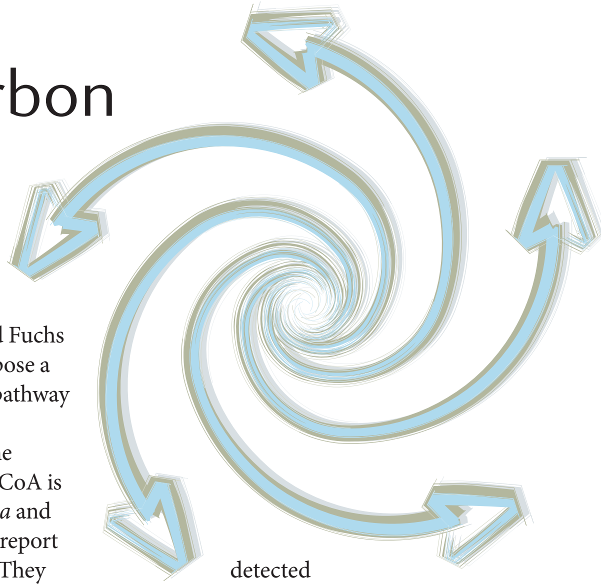
MICROBIAL PHYSIOLOGY

Five ways to cycle carbon



Autotrophs participate in the carbon cycle by fixing carbon dioxide to produce the biomass that all other organisms use for life. Four autotrophic carbon-fixation pathways were already known and Berg *et al.* now report a fifth pathway that is used by archaea from diverse habitats.

The best-known autotrophic pathway is the Calvin–Bassham–Benson cycle, which is present in plants, algae, cyanobacteria and proteobacteria. A second autotrophic pathway (Arnon–Buchanan cycle) uses a reductive citric acid cycle and is found in anaerobic or microaerophilic bacteria and archaea. A third autotrophic pathway (Wood–Ljungdahl pathway) uses a reductive acetyl-CoA pathway and is only found in strictly anaerobic bacteria and archaea. A fourth pathway uses the 3-hydroxypropionate cycle.

The latest research builds on previous work from the Fuchs laboratory, which showed that enzyme activities of the 3-hydroxypropionate cycle are upregulated during autotrophic growth of the archaeon *Metallosphaera sedula*, thereby supporting a role for this cycle in carbon fixation. The first reaction in the 3-hydroxypropionate carbon dioxide-fixation cycle is the carboxylation of acetyl-CoA; the carbon dioxide acceptor is then regenerated in a cyclic process, with 3-hydroxypropionate and malyl-CoA as intermediates. An inability to detect the regeneration of acetyl-CoA from succinyl-CoA during autotrophic growth of *M. sedula* led Fuchs and co-workers to propose a modified form of this pathway in this autotroph.

Berg *et al.* tackled the problem of how acetyl-CoA is regenerated in *M. sedula* and other archaea and now report their results in *Science*. They formulated a working hypothesis that succinyl-CoA is reduced to 4-hydoxybutyrate, which is then converted into two molecules of acetyl-CoA by 4-hydroxybutyryl-CoA dehydratase, an oxygen-sensitive enzyme that they detected in the genomes of many of the autotrophic archaea that have been sequenced to date. Cell extracts of *M. sedula* catalysed the conversion of succinyl-CoA to 4-hydroxybutyrate in the presence of NADPH, and converted 4-hydroxybutyrate to acetyl-CoA if MgATP, CoA and NAD were supplied. They named this autotrophic pathway the 3-hydroxypropionate/4-hydroxybutyrate assimilation pathway.

When *M. sedula* was grown on a mixture of hydrogen, oxygen and carbon dioxide, the enzymes that are required for the conversion of succinyl-CoA to acetyl-CoA were detected and, subsequently, purified. Using peptide sequences from these proteins they detected the cognate genes in the sequenced genome and used these gene sequences to identify similar genes in other Sulfolobales genomes. All of these autotrophic archaea are microaerophiles or anaerobes.

Importantly, 189 partial or complete 4-hydroxybutyryl-CoA dehydratase gene sequences were found after searching the Global Ocean Sampling dataset; mesophilic marine archaea that fix carbon by this new pathway might make a considerable contribution to the global carbon cycle.

Susan Jones

ORIGINAL RESEARCH PAPER
Berg, I. A., Kockelhorn, D., Buckel, W. & Fuchs, G. A 3-hydroxypropionate/4-hydroxybutyrate autotrophic carbon dioxide assimilation pathway in archaea. *Science* **318**, 1782–1786 (2007)