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# The thermodynamic drivers of atmospheric chemical disequilibrium and their relationship to habitability

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Lovelock (1965) proposed that the presence of chemical disequilibrium in a planetary atmosphere could be used to infer the existence of life. This idea has an increasing relevance to today's science as we begin to obtain spectroscopic data about exoplanets' atmospheres.

However, disequilibrium can be driven by abiotic photochemical and geological processes as well as biological ones, and as a consequence we need to develop theoretical tools that will allow us to distinguish between these cases. A primary result of our analysis is that the extent of chemical disequilibrium is uninformative by itself, since an atmosphere far from equilibrium can be the result of slow processes building up over time rather than rapid on-going processes. However, if it is possible to estimate the kinetics of a planet's atmospheric chemistry then one can infer the amount of power that must be supplied to the process that drives the disequilibrium. A high power is more indicative of a biological driving process such as photosynthesis.

Earth's atmosphere contains both molecular oxygen and methane, supplied continually by photosynthesis. These react in the atmosphere to form $CO_2$ and water. We show using a simple model that adding these reactants and removing the products from the atmosphere requires around $2 \times 10^9$ W of power. This power is continually dissipated by the oxidation of methane, and so at least this amount of power must be supplied as work in order to maintain the disequilibrium. It will be possible to perform similar calculations for the atmospheres of exoplanets once better data about the composition and probable kinetics of their atmospheric chemistry becomes available. A similarly high figure would be very suggestive of the presence of a biosphere.